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CARBON DIOXIDE EVOLUTION OF SOIL AND CROP GROWTH

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INTRODUCTION

Carbon dioxide evolution from the soil, and its relation to microbiological activity and to climatic factors have been studied by a large number of scientists (17, 34, 32, 33, 25, 6, 29), who have found a relation between the carbon dioxide evolution on one hand and the number of bacteria and the intensity of nitrification on the other hand. The influence of mineral salts, humidity, manure, and temperature on the rate of carbon dioxide evolution has been studied by Wollny (36), Petersen (25), König and Hasenbäumer (10), Van Suchtelen (33), Lundegårdh (16, 17), Waksman and Starkey (34), and others.

Most of the investigators cited above have worked with soil samples in the laboratory. After treatment with water, salts or manure a portion of 1 kgm. or less of soil was placed in a vessel and a stream of CO_2-free air was passed through the soil. The evolved carbon dioxide was determined åfter absorption in alkali (32).

Potter and Snyder (27) and Neller (23) first passed the CO_2-free air continuously over the surface of an enclosed soil sample. Lundegårdh (16) put 100 gm. soil into a 1000-cc. Erlenmeyer flask and measured volumetrically the accumulation of carbon dioxide in the flask air after 24 hours. For analysis, a 10-cc. sample of air was sucked into an apparatus of simplified Haldane type (fig. 1). This method permits work on a large scale because the flasks can be put easily into thermostats without any special arrangement for streaming air. In general, methods where the carbon dioxide is allowed to escape from the soil by means of diffusion are to be preferred to methods where an air stream passing through the soil is used. In nature, free diffusion is the chief factor in the liberation of the carbon dioxide that is accumulated in the pores of the soil (28; 17, p. 156).

THE SOIL RESPIRATION

For studies on the relation between carbon dioxide evolution and climatic factors and crop production a method is needed for estimating the "soil respiration," or the amount of CO_2 that is given off in one hour from one square meter of the soil in situ. The author used the following method (16; 17, p. 146):

The "respiration bell," consisting of a conic zinc vessel with a cylindric edge and a tube *sr* at the top (fig. 2), has an open width of 750 sq. cm. The edge *e* is 6 cm. high and the conic part 10 cm. high. When the edge is driven into the soil, the volume of air enclosed over *u* in the bell is about 2300 cc. Before the beginning of the experiment the surface of the soil must be smoothed in order to avoid errors in the air volume. The inside of the bell is coated with paraffin to avoid absorption of CO_2.

After 10 to 20 minutes a small sample of the bell-air is taken into an apparatus for volumetric analysis of carbon dioxide. The author has constructed a new apparatus that permits

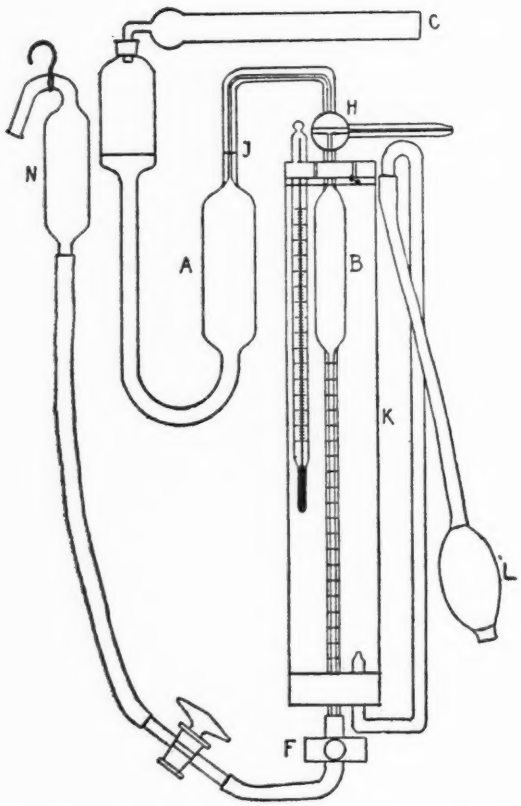


FIG. 1. SIMPLE APPARATUS FOR ANALYZING THE CO_2 CONCENTRATION OF THE AIR

B, gas burette; *A*, absorption vessel (with 20 per cent KOH solution); *I*, index; *N*, mercury vessel; *F*, screw for adjusting; *L*, rubber ball for blowing air through the water mantle *K*.

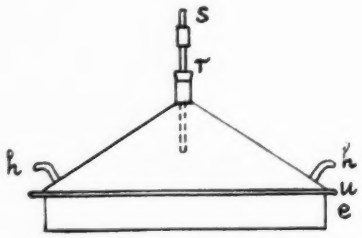


FIG. 2. APPARATUS FOR ESTIMATING THE SOIL RESPIRATION ("RESPIRATION BELL")

h, handles; *e*, cylindric edge; *u*, ring up to which *e* is driven in the soil; *sr*, tube for drawing the air sample.

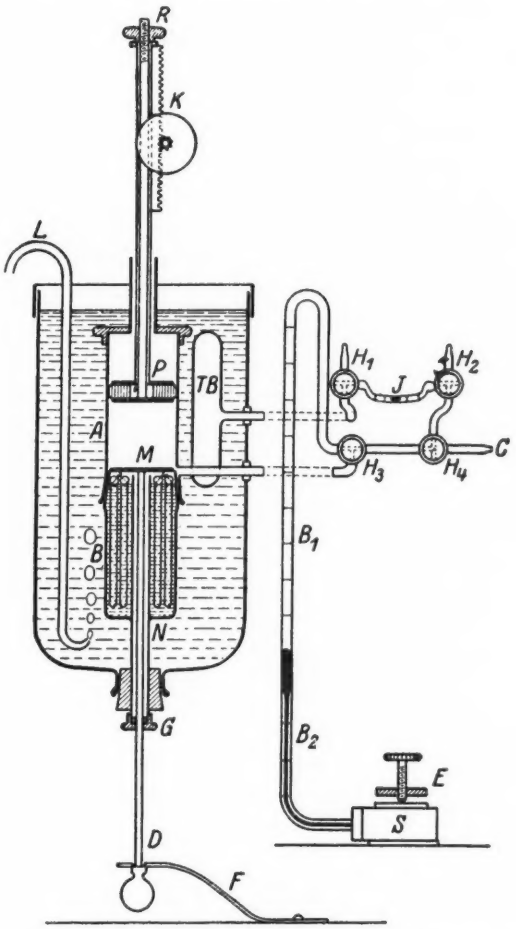


FIG 3. SCHEME OF NEW APPARATUS FOR ACCURATE ANALYSIS OF THE CO_2 CONCENTRATION IN THE AIR

A, glass cylinder; *P*, air-tight piston for filling *A* with the air sample; *B*, absorption vessel with 12 per cent KOH + 3 per cent $Ba(OH)_2$, air-tight connected with *A; M*, metal lid for *B*, attached to the stick *MD*, and provided with glass rods dipping into the absorption solution in *B; N*, glass tube in which *MD* is moving; *G* air-tight packing for *MD; TB*, thermobarometer for compensation of variations in air pressure and temperature; *J*, index of petroleum; B_1 B_2, burette; *S*, rubber vessel filled with mercury; *E*, screw for adjusting the mercury stand in B_1B_2. For making the determinations see (18, p. 203).

analyses in the field with an error in single observations of only 0.003 per cent CO_2 (18, p. 203, Ab. 2). This apparatus is portable and can be placed on portable stand (fig. 3 and plate 1, fig. 1). A higher CO_2 concentration than 1 per cent in the soil atmosphere may become dan-

gerous to crop growth not only because the growth rate is retarded, but because certain parasitic fungi, as *Fusarium culmorum*, are stimulated, causing increased infection (15).

The calculation of the soil respiration from the estimated value of the carbon dioxide concentration in the bell is carried out by means of the formula

$$\frac{(a - b) \times 1.858 \times 2300 \times \frac{60}{t}}{750} = x \text{ (in gm. to the hour for each square meter)}$$

where a is the CO_2 concentration in the bell-air at the beginning, b at the end, calculated in per cent, t the time in minutes, 1.858 the weight of 1 liter CO_2 at 15°C. and 760 mm. pressure, 2300 the volume of the bell, and 750 the soil surface under the bell. Corrections for air pressure and temperature are applied as usual.

The formula is valid as long as $a - b$ is proportional to the time t. Special tests have shown that this is approximately true for 20 minutes, after which the accumulation of carbon dioxide in the bell-air causes a diminution of the rate of diffusion from the soil (16, p. 150).

TABLE 1

Soil respiration on various soils

UNTREATED SOILS	DATE	SOIL RESPIRATION PER SQUARE METER PER HOUR
		gm.
Sandy soils (low humus content)	August 26, 1922	0.206
Sandy soil (4 per cent humus)	August 26, 1922	0.399
Sandy loam	February 9, 1921	0.317
Loam	November 17, 1922	0.397
Loam (10 to 15 per cent humus)	June 19 to September 13, 1923	0.411
Clay soil	June 23 to October 10, 1925	0.125
Alder forest	August 13, 1922 and October 10, 1921	1.170 to 2.340
Beech forest	August 31, 1920	2.20 to 1.54
	October 10, 1921	0.33 to 0.83
Alder swamp	October 10, 1921	0.28
Meadow with *Nardus* and *Carex*	October 10, 1921	0.33

Averages of several determinations.

In the years 1921 to 1925 the author made a great number of determinations of the soil respiration. On agricultural soils in South Sweden the respiration varied between 0.125 and 0.411 gm. to the square meter in an hour. Light sandy soils with low humus content showed a minimum respiration. The highest values were obtained on loam with 10 to 15 per cent humus (table 1). A heavy clay soil from fertile Skåne county showed a very low respiration.

Forest soils evolve in general much more carbon dioxide than agricultural soils or grass land. The difference is probably due to the greater porosity and more uniform humidity of the forest soils. The activity is always highest in the upper layer of the soil, but in the cultivated fields the periodical desiccation and the high light intensity must act very unfavorably on the microbiological processes in the soil surface.

THE CARBON DIOXIDE CONCENTRATION IN THE SOIL AIR

The soil respiration is the total of all soil processes in which carbon dioxide is produced. Pure chemical oxidation will probably always occur (8, 10) but as a rule only to a small extent. The microflora (bacteria, actinomyces, fungi) produce the chief part of the carbon dioxide, but the plant roots in many cases also are giving off considerable quantities of this gas.

The respiration from a bare soil and that from the same soil covered with oats were compared. The former showed a respiration of 0.268 gm. and the latter a respiration of 0.399 gm., a difference of 0.131 gm.; the root respiration thus forms about 30 per cent of the total soil respiration. Further experiments indicated, however, that a great deal of what we call root respiration is due to bacteria that inhabit the root surface and probably are fed with the organic substances that are delivered from the roots (7, 35, 20).

Oats and wheat were cultivated in sterilized soil and in non-sterilized soil. The roots from the non-sterilized soil evolved about 45 per cent more carbon dioxide per unit dry substance than the roots from the sterilized soil. A kind of "Rhizosphere" (9) probably must be assumed and the total root respiration is the sum of the respiration of the living root cells and of the microörganisms that live in contact with the root surface or in the vicinity of the roots.

The carbon dioxide concentration in the soil air (the pore space) is a function: first, of the absolute CO_2 production of the soil particles and the roots (A), and secondly, of the diffusion velocity. An expression for the latter is: the diffusion coefficient K = the volume of gas (in cc.) that in 1 second passes through a cylinder of 1 sq. cm. base and 1 cm. height, when the difference in partial pressure is 1 atmosphere. In physics, K is used as a property of the diffusing gas. K here will be used for characterising the medium and will be defined as "the diffusion value of the soil" when the diffusing gas is carbon dioxide.

The simplest relation between the absolute CO_2 production (A), the diffusion value (K), and the CO_2 concentration in the soil air (C) is

$$C = k \cdot \frac{A}{K}.$$

C alone can never be used as an adequate expression for the soil activity.

For measuring C Pettenkofer (26), Fodor (5), Lau (11), and Russel and Appleyard (29), have used rather complicated experimental arrangements that cannot be used far from the laboratory. Romell (28) introduces the microgas-analysis apparatus of Krogh. For drawing the gas samples he uses a thin brass tube of special construction that is put into the soil; the sample is collected in small glass tubes. The Krogh apparatus is good in cases where the air content in the soil is very small. For ordinary soils the gas-analysis-apparatus mentioned above (fig. 1 or 3) gives far more accurate values. The sample is drawn directly into the analyzing apparatus. The construction of

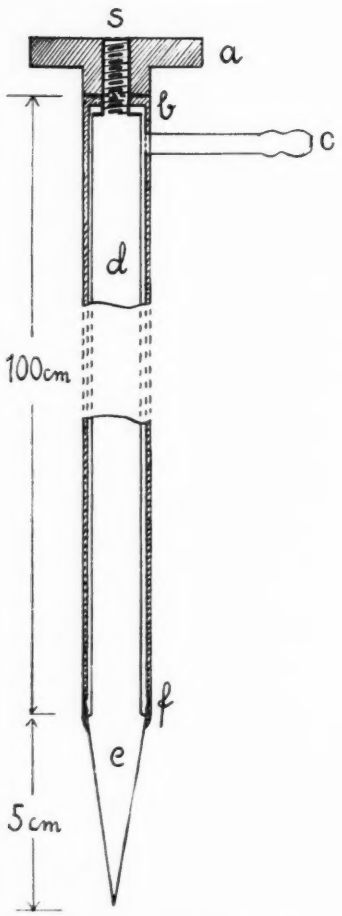


FIG. 4. TOOL FOR DRAWING AIR-SAMPLES FROM THE SOIL

A brass tube *bf*, about 1 cm. in diameter, is provided at the upper end with a small tube *c*, which is connected by a rubber tube with the analyzing apparatus. The steel rod *sde* with its conic end *e* fills up *bf*, but the air can circulate between rod and tube wall; *e* is moving tight, but 2 mm. above the edge of the conic part (at *f*) the tube wall is hollowed out. When therefore *sde* is drawn back a few mm. by aid of the screw *s* and the nut *a*, the air can pass through. Before drawing the sample, *e* must be lowered below *f*. The stick is then driven into the soil to the desired depth (usually 15 cm.). Then *e* is elevated until the upper end of *d* hits the lid of the brass tube. This closure is then air-tight while the air can pass by *f*.

the brass tube used for drawing the samples is shown in figure 4. The analysis apparatus is connected with the mouth-piece *c* by a thin rubber tube, as shown in plate 1, figure 1.

In connection with the field experiments at the station many determinations of the CO_2 concentration in the soil atmosphere have been made (17, p. 167 seq.). Only a brief review of the results can be given here.

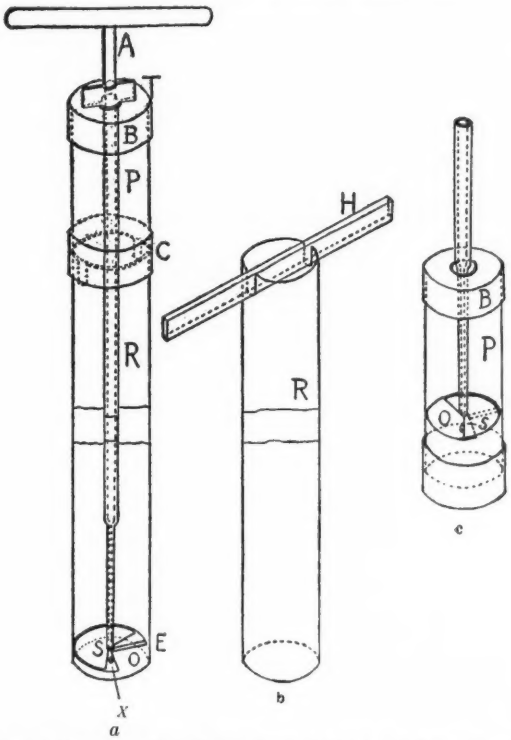


FIG. 5. BORER FOR DRAWING SOIL SAMPLES OF A DEFINITE VOLUME FROM DIFFERENT DEPTHS

It consists of two parts *R* and *P*, the former is the borer proper: a steel tube of about 1½ inches diameter and 3 feet in length. *R* has at the upper end two scores, in which the iron handle *H* is placed. The lower end is ground to an edge. When *R* has been bored into the soil, the shorter tube *P* is put on it and the boring arrangement *AS* is applied. This consists of a steel plate *E* with a sector carving at *O*, attached to a steel rod *A*. When the handle *A* is turned around, *E* will bore itself into the soil, because one side of the carving is bent down as an edge. On the steel plate another plate sector *S* is sliding. *AS* is attached to a brass tube *ST* that surrounds the rod *A*. When *E* has been bored down to the edge of *R* the small handle *T* is turned so that *S* covers *O* (see *c*). When the whole boring arrangement then is drawn back, the soil sample will slip with it. *P* is then detached from *R* and the sample is put into a box or flask.

As already stated by Lau, Russel and Appleyard, Romell, and others, the CO_2 concentration increases with the depth below the soil surface. In 15 cm. depth, *C* averages about 0.3 per cent for lighter soils, but may arise to 1

per cent or more, especially in wet soils rich in humus. Even in the same field the variation from plot to plot may be very prominent, especially in soils that are not well cultivated and contain lumps of decomposing organic matter. This is another reason why C ought not to be used as an indicator of the soil activity.

The C values are important for estimating the growth conditions of the plant roots. It is a well-known fact that higher CO_2 concentrations have an injurious effect on roots (28, 15). The resistance of different plants varies greatly. General statements of this poisonous concentration are, therefore, of no great value; the available facts seem, however, to indicate $C = 1$ per cent as the lower limit for alteration (28; 17, p. 164).

By determining the CO_2 concentration at 15 cm. depth, one can therefore detect an unhealthy condition of the soil that can be removed by cultivation, drainage, or other measures for increasing the aeration of the soil.

TABLE 2

CO_2 production in the profile of a sandy soil

DEPTH	CO_2 PRODUCED TO THE SQUARE METER IN 1 HOUR	K
cm.	*gm.*	
0–10	0.271	0.0644
10–20	0.084	0.0237
20–30	0.016	0.0128
30–40	0.009	
S:a.....	0.380	
Direct determination of the total soil respiration.....	0.345	

CO_2 PRODUCTION AT DIFFERENT DEPTHS

For many purposes it is important to know the vertical distribution of the processes bringing about the evolution of CO_2. With a borer of special construction (fig. 5) definite volumes of soil are drawn from different depths. The samples are taken to the laboratory in closed flasks and the free evolution of carbon dioxide from them is measured in the manner previously described (p. 417). After reducing the activity to unit soil volume and time the activity of the whole soil profile is reconstructed, as shown in table 2.

This experiment which has been repeated several times, makes clear: first, that almost all the CO_2 produced in the soil is given off from the soil surface; and secondly, that the moving force of the soil respiration is the diffusion.

In the case cited in table 2 the soil activity is concentrated in the surface layer and decreases very rapidly with the depth. In other cases the upper 30 cm. of the crust respire more uniformly. When the soil is manured the layer where the rotting dung lumps are lying reveals the highest activity.

DIFFUSION VALUE, AN INDICATION OF SOIL AERATION

The estimation of the total soil respiration, the absolute activity of the profile, and the CO_2 concentration in different depths enable us to calculate the diffusion value K of a stratum of the soil.

We assume that the soil is composed of several strata, S_1, S_2, S_3, etc. (fig. 6). The activity of these strata is a_1, a_2, a_3 (calculated in cubic centimeter per hour and per square centimeter base). As the carbon dioxide diffuses upward, the CO_2 quantities $a_1 + a_2 + a_3$, $a_2 + a_3$, and a_3 cubic centimeters are moving through S_1, S_2, and S_3. Finally the CO_2 concentrations b, at p_1, p_2 and p_3 have been determined (fig. 6).

If the thickness of the stratum S_2 is y_2 cm. the following equation results:

$$K = \frac{(a_2 + a_3) \cdot y_2 \cdot 100}{3600 \cdot (b_2 - b_1)}.$$

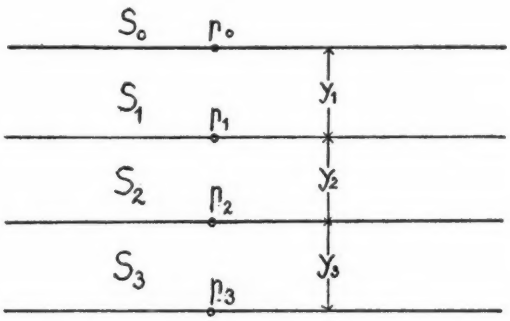


FIG. 6. SOIL STRATA

In a similar manner K is calculated for the other strata. The equation, of course, gives approximate values of K, but the error diminishes with y. In practice, determinations with smaller values of y than 5 to 10 cm. are difficult to carry out. In table 2 the K values of three strata are given.

The estimation of the diffusion values of different strata of course gives a much more adequate idea of the aeration of the soil than a determination of the average K value. Especially with forest soils it seems necessary to take into consideration the stratification, which in this case may be very prominent. Agricultural soils also may be less aerated in lower strata, as shown in table 2.

In general the structure of cultivated soils is more uniform; for practical purposes, therefore, a simplification of the formula seems justifiable. Only C at 15 cm. depth and the total soil respiration A are thus measured. After calculation of the latter in cubic centimeters to the hour (Aa) the formula will appear in this way:

$$K = \frac{Aa \cdot 15 \cdot 100}{3600 \cdot (C - 0.03)}$$

where K equals the approximate diffusion value of the upper 15 cm. of the soil. K increases with increasing A and decreases with increasing C. Assuming that the average A = 0.4 gm. and C = 1.0 per cent, the value of K = 0.009, which is the minimum for the normal aeration (cf. p. 424). In good soils K is always considerably higher (table 3). When A is higher than 0.4 gm., as in most forest soils, the minimum for the normal aeration is correspondingly raised.

The method for expressing and measuring the aeration of the soil is based upon the experimentally proved fact that diffusion is the moving force of the

TABLE 3

Diffusion value K

	C	*A*	*K*
	per cent	*gm.*	*gm.*
Loam, 1922	0.18	0.397	0.060
Sandy loam, 1921	0.30	0.399	0.033
Loam rich in humus, 1923	0.68	0.411	0.014
Alder forest	1.02–1.80	2.34	0.051–0.029

TABLE 4

Fluctuations of soil activity during the vegetation period

DATE	AVERAGE TEMPERATURE*	RAINFALL	CO_2 CONCENTRATION 4 M. ABOVE THE SOIL SURFACE†	CO_2 CONCENTRATION 15 CM. BELOW THE SOIL SURFACE‡	DIFFUSION VALUE§	SOIL RESPIRATION PER SQUARE METER PER HOUR
1923	°C.	*mm.*	*mgm. per l.*	*volume per cent*		*gm.*
June 19	12.6	0.0	0.543	....	.....	0.456
June 29	12.0	4.1	0.567	0.39	0.031	0.443
July 10	20.9	5.9	0.544	0.46	0.0199	0.378
July 24	14.6	26.8	0.522	0.84	0.010	0.370
August 10	17.5	55.9	0.568	....	.....	0.438
August 21	12.5	18.2	0.596	0.59	0.018	0.435
September 4	11.0	67.8	0.625	....	.....	0.412
September 13	10.4	26.1	.....	1.26	0.010	0.540

* According to thermographical record.

† Average of 71 daily analyses at the station near the seashore.

‡ Each value averages from 9 to 16 observations.

§ According to formula, page 425.

gas exchange between the soil and the atmosphere. Earlier efforts to measure the soil "permeability" (21, p. 171 seq.) have no great practical value since the gas is determined *under pressure*.

The aeration of the soil is the upward diffusion of carbon dioxide and the downward diffusion of oxygen. As a rule the amount of oxygen absorbed by the soil is equal to the amount of carbon dioxide given off. Therefore the diffusion value of carbon dioxide is a very good measure for the total aeration. Exceptions to the rule occur in very badly aerated soils (12, 28); here the oxygen absorption is usually greater than the carbon dioxide liberation.

After the soil is treated with lime, the evolution of carbon dioxide is diminished because of chemical combination. Normally only very little carbon dioxide is retained in the soil or escapes with the ground water.

The method is rather simple: the determination of the soil respiration (fig. 2) takes about 20 minutes; while the carbon dioxide is accumulating in the respiration bell, the air sample from 15 cm. depth can be drawn. A and C are important not only for calculating K, but also in connection with soil fertility and pathology. The methods described in this paper are useful in studying the condition of the soil, especially in the case of a number of nonparasitic

TABLE 5

Fluctuations of soil activity during the vegetation period

DATE	AVERAGE TEMPERATURE	TEMPERATURE 5 CM. BELOW THE SOIL SURFACE	RAINFALL	CO_2 CONCENTRATION 4.5 M. ABOVE THE SOIL SURFACE	CO_2 CONCENTRATION 0.25 M. ABOVE THE SOIL SURFACE	SOIL RESPIRATION PER SQUARE METER PER HOUR
1925	*°C.*	*°C.*	*mm.*	*mgm. per l.*	*mgm. per l.*	*gm.*
June 23–26	16.15*	.....	34.0	0.571†	0.5948‡	0.160§
June 29–July 1	19.1	.....	0.0	0.624	0.6480	0.180
July 7–9	16.98	.....	13.0	0.656	0.6474	0.188
July 13–15	20.4	.....	0.0	0.671	0.6580	0.256
July 23–24	23.3	19.8–20.0	0.0	0.664	0.5962	0.228
July 28–29	14.4	19.0–18.6	24.0	0.611	0.6025	0.200
August 4–5	18.1	16.7–16.2	2.0	0.581	0.5764	0.246
August 11–13	18.3	19.5–17.1	7.0	0.776	0.7640	0.192
August 19–20	17.3	15.7–15.0	9.0	0.717	0.7441	0.318
August 26–27	16.1	16.0–15.4	4.0	0.559	0.6088	0.148
September 1–2	11.9	14.3–13.5	39.0	0.585	0.6200	0.246
September 10–12	10.0	11.2–10.7	28.0	0.570	0.5795	0.188
September 15–17	13.0	11.2–12.2	2.0	0.567	0.5677	0.204
September 22–24	11.6	12.1–12.5	12.0	0.575	0.5844	0.160
September 29–October 1	10.8	11.6–11.3	10.0	0.597	0.6152	0.290

* Air temperature according to thermographical record. Average for 1 week.

† Average for 1 week, from the field laboratory.

‡ Average for 1 week, from 9 parallel plots of the experimental field (thus 50 to 60 single analyses each).

§ Average for 2 days from 5 parallel plots. Each single observation duplicated (thus 20 single analyses each).

diseases and the conditions for infection by Fusarium and other organisms in the living soil (15).

THE SOIL RESPIRATION UNDER THE INFLUENCE OF CLIMATIC CONDITIONS AND FERTILIZERS

Seasonal fluctuations

Several investigators have stated that the urea-decomposing and the nitrogen-fixing powers of the soil (13, 22) and the number of bacteria (3) reveal seasonal fluctuations.

The curves show maxima in spring and fall and a depression in summer. Russel and Appleyard (29) obtained a similar curve for the carbon dioxide concentration in the soil atmosphere. Similar periods have been recorded for water organisms (4, 24).

Hitherto investigations concerning seasonal fluctuations of the total soil

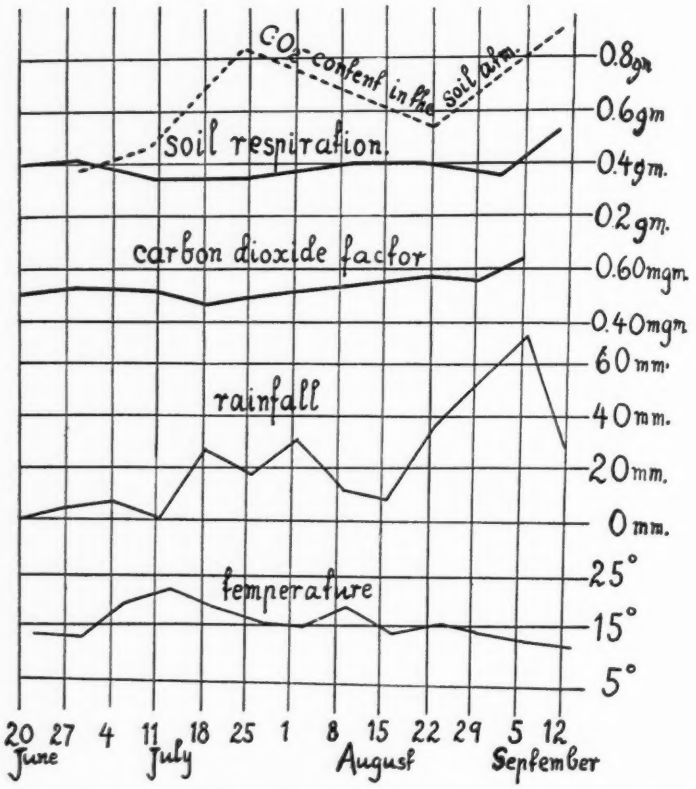


FIG. 7. SEASONAL FLUCTUATIONS OF THE SOIL RESPIRATION, CARBON DIOXIDE CONCENTRATION AMONG THE LEAVES, CARBON DIOXIDE CONTENT IN THE SOIL AIR, AND CLIMATIC FACTORS—OATS, 1923

activity have failed. The author's observations include only the vegetation period (tables 4 and 5, and figs. 7 and 8).

The most striking thing about the two curves in figures 7 and 8 is the lack of, or the incomplete, correlation between CO_2 factor and the temperature. The temperature of the upper 5 to 10 cm. where the maximal activity is located follows fairly closely the temperature of the air recorded about 15 cm. above

the soil surface (table 5), but the amplitude of the fluctuations is smaller. Nevertheless the rise in the temperature curve in July, 1923 (fig. 7) does not induce an increase in the soil respiration. In 1925 a certain correlation perhaps exists, but the remarkable increase of the soil respiration in the middle of August is apparently not due to the temperature.

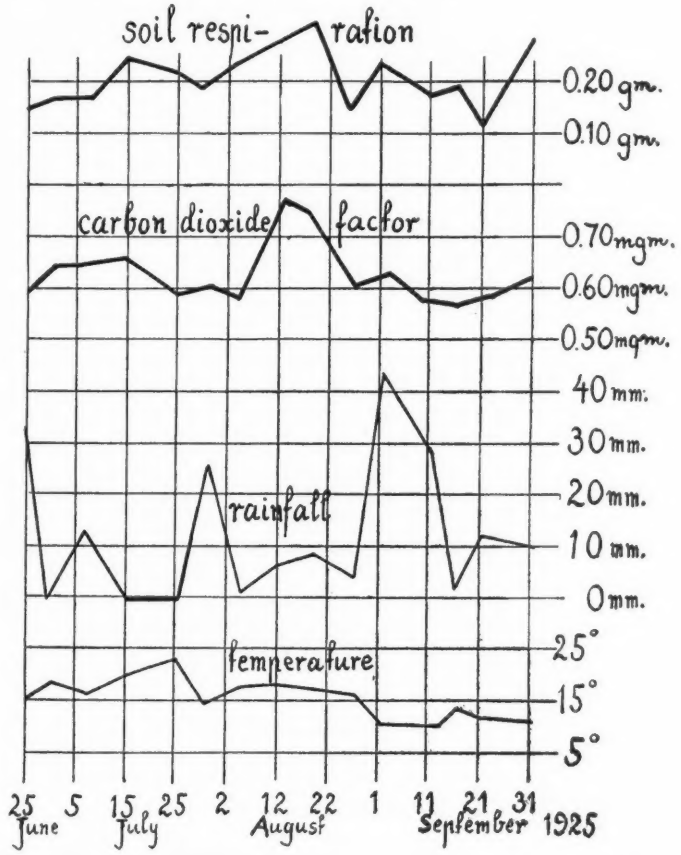


FIG. 8. SEASONAL FLUCTUATIONS OF SOIL RESPIRATION, CARBON DIOXIDE FACTOR, AND CLIMATIC CONDITIONS—SUGAR BEETS, 1925

Even rainfall is not correlated to any great extent with the total soil activity. That, on the other hand, the concentration of the carbon dioxide in the soil atmosphere and therefore also the diffusion value, rise with the soil water (fig. 7) is not surprising, because the air content in the soil decreases with increasing water content.

Both curves for the soil respiration, for 1923 and 1925, show a slight maximum in August, and both have a steep rise in September, in accord with earlier statements on bacterial activity. The cause of this periodicity is as yet unrevealed. The competition between the different types of the soil population and also the relations between microörganisms and the growing crop probably cause fluctuations in the activity, but the power of the single components in this very complicated process cannot be traced exactly (30, p. 279; 17, p. 179).

Action of fertilizers and manure

Organic matter is the source of carbon dioxide evolution, hence the humus content in soil is always a factor in the process of soil respiration. Very frequently the humus content is a factor in the maximum, hence its relative influence is small. If a humus content of 3 per cent is assumed, one hectare of soil will contain about 200,000 kgm. organic matter, which is equivalent to about 300,000 kgm. carbon dioxide. A cultivated field of this size evolves about 10,000 kgm. of carbon dioxide a year. It is easy to understand why a rise in the humus content above about 3 per cent will not change the soil respiration to any extent. As previously stated, the low respiration of poor sandy or clay soils with a low humus content is partly due to the fact that the organic matter here begins to act as a limiting factor. The author has found, however, that even in such poor soils the soil respiration will increase when mineral salts are added. The humus content itself will therefore probably very seldom act as an absolute limiting factor. When we find that the application of farmyard manure frequently changes the rate of carbon dioxide evolution, we must, as a rule, look for other causes than the increase in absolute humus content.[1]

In the author's field experiments during 1921 to 1925, 10,000 to 65,000 kgm. of farmyard manure was given per hectare, and the soil respiration in the succeeding season was studied in comparison with control plots. The results from 1921 to 1923 are fully treated in previous papers (16, 17), briefly reviewed herewith.

When small and medium quantities of farmyard manure were added in the spring to sands or loams not too poor in humus, the effect upon the soil respiration was surprisingly small. The dunged plots at first evolve less carbon dioxide than the control plots, then the respiration again rises.

Large quantities of manure always increase the soil respiration (fig. 9), but the action of the manure seems to decline. The results seem to indicate the following theory: The native microörganisms of the farmyard manure persist only when large quantities are given, so that the manure is composed of coherent lumps. If the manure is uniformly spread out among the soil particles, the original environment of the manure organisms is destroyed and it will take some time for them to invade the new substrate. Part of the action of the manure is undoubtedly due to the amount of ammonia and other inorganic components (1). Moreover

[1] A rather large quantity of manure—45,000 kgm. per hectare—was added to a soil containing about 3 per cent organic matter.

the manure contains many different organic components that may act as stimulants or have a retarding effect on the soil microörganisms. Very little, however, is known about that.

The favorable effect of certain mineral salts used in the common artificial fertilizers has already been stated. The author's extensive field experiments from 1921 to 1925 prove the importance of mineral salts for increasing the soil activity (17, p. 190–197). In table 6 a selection of these experiments is summed up.

The pronounced effect of the manure in the sugar beet field in 1925 may be caused by the low humus content and the dense structure of the clay soil. The absolute activity of this soil was not equal to half of that of the sandy loam rich in humus. The estimations may have been made over a spot where the fertilizer was not well distributed.

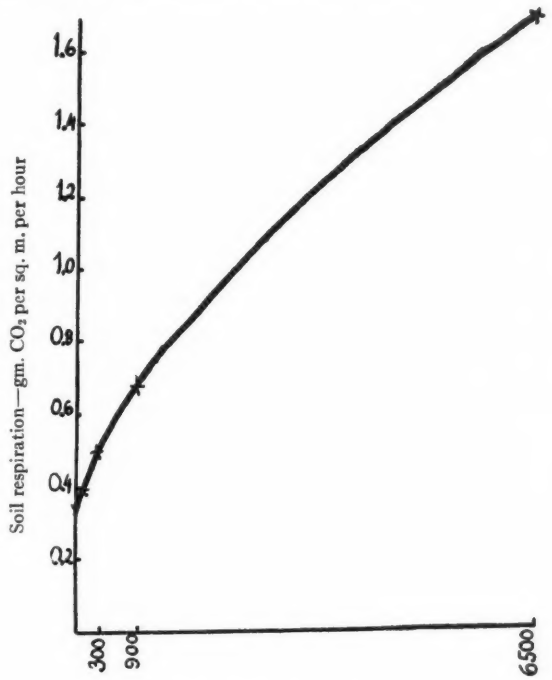


FIG. 9. THE EFFECT OF LARGE QUANTITIES OF FARMYARD MANURE ON THE SOIL RESPIRATION

SOIL RESPIRATION AND CROP GROWTH

The carbon dioxide concentration in the atmosphere as a growth factor

The importance to agriculture of the soil respiration lies in the fact that the carbon dioxide concentration in the atmosphere among the plant leaves is at a minimum (17). Rather small variations in the carbon dioxide content of the atmosphere involve corresponding variations in the rate of carbohydrate assimilation and growth.

TABLE 6

Increase in soil activities due to mineral salts

SOIL	CROP	FERTILIZER PER 100 SQ. M.	SOIL RESPIRATION PER SQUARE METER PER HOUR		TIME
		kgm.	*gm.*	*per cent*	*1922*
Sandy loam, 10 per cent humus	Cabbage	No fertilizer	0.28*	100	July 11 to August 8
		3–superphosphate 2–40 per cent potassium chloride 3–sodium nitrate	0.83	297	July 11 to August 8
		3–superphosphate 2–40 per cent potassium chloride 3–sodium nitrate 600–farmyard manure	1.0	357	July 11 to August 8
					1923
Sandy loam, 10 per cent humus	Oats	No fertilizer	0.411	100	June 19 to September 13
		3–superphosphate 3–40 per cent potassium chloride 3–sodium nitrate	0.468	114	June 19 to September 13
		3–superphosphate 3–40 per cent potassium chloride 3–sodium nitrate 300–farmyard manure	0.515	125	June 19 to September 13
					1925
Clay, soil, fertile	Sugar beets	No fertilizer	0.125	100	June 23 to October 1
		4–superphosphate 4–40 per cent potassium chloride 4–sodium nitrate	0.150	120	June 23 to October 1
		4–superphosphate 4–40 per cent potassium chloride 4–sodium nitrate 200–farmyard manure	0.152	121.5	June 23 to October 1
		4–superphosphate 4–40 per cent potassium chloride 4–sodium nitrate 400–farmyard manure	0.154	123	June 23 to October 1
		400–farmyard manure	0.190	152	June 23 to October 1

* These values are the averages of a great number of observations in the periods mentioned.

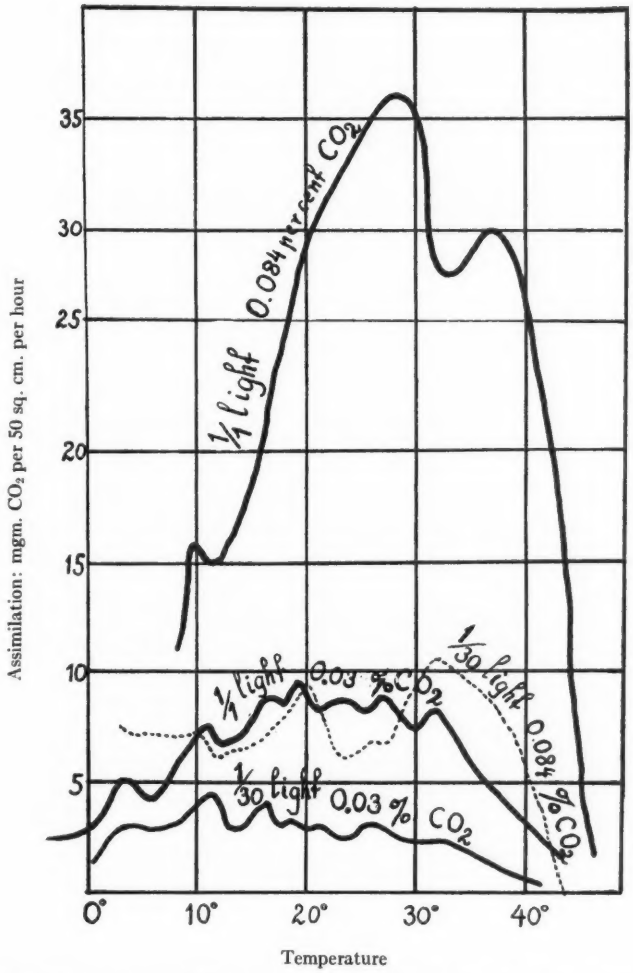


FIG. 10. THE CARBOHYDRATE ASSIMILATION OF LEAVES OF SUGAR BEETS IN RELATION TO THE FACTORS OF LIGHT, CARBON DIOXIDE, AND TEMPERATURE

The light intensity 1/1 is full daylight (sun + diffuse light), 0.03 per cent is the "normal" concentration of carbon dioxide in the atmosphere.

The influence of light, temperature, and carbon dioxide concentration upon the process of assimilation has been discussed (18). Figure 10 shows the results of a series of experiments with sugar beet leaves made in the summer of 1925 and not yet published. The curve system shows clearly the following peculiarities, stated in a previous paper (18):

1. A rise in the carbon dioxide concentration involves an increase in the assimilation not only with maximum light but also at low light intensity (one-thirtieth of full daylight).

2. The temperature optimum of the assimilation is at no fixed point, but is a function of the other factors, so that in general the optimum lies at a lower temperature when the intensity of light and the carbon dioxide factor are diminished.

3. A low light intensity (one-thirtieth of the full daylight) can be compensated by a high carbon dioxide concentration (0.084 per cent).

4. The quotient of utilization $Ak = \frac{\Delta E}{\Delta F}$ — where ΔE is the rise in assimilation intensity obtained when the carbon dioxide concentration is raised the small amount ΔF—is not constant in the whole temperature province, but is higher at 30° than at 20°, when the light is full.

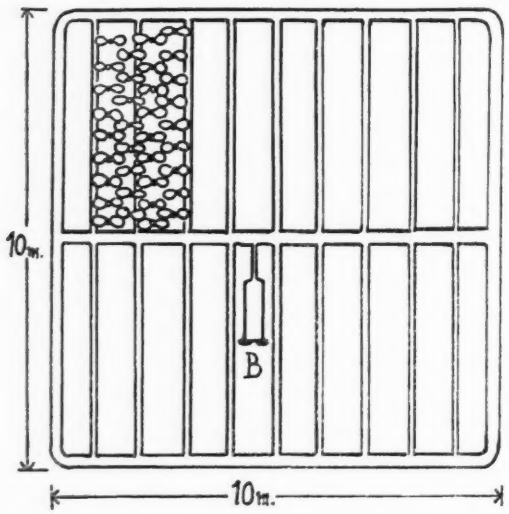


FIG. 11. SYSTEM OF PERFORATED IRON TUBES FOR GASSING OF FIELD PLOTS
B is the steel flask containing carbon dioxide

As carbohydrate assimilation is the chief nutrition process in the plant, the circumstances mentioned here will be of great importance in the understanding of plant growth. This has been proved by experiments in the field or in glass houses, where the amount of carbon dioxide in the atmosphere among the plant leaves was varied.

In 1922 and 1923, experiments with CO_2 fertilization were carried out in the field. For this purpose five 100-sq. m. plots were provided with systems of iron tubes, perforated and connected with a steel flask containing pure carbon dioxide (fig. 11). Five plots of the same size served as controls; all were cultivated with the same crop and were otherwise uniformly treated. The results given in table 7 show a clear positive effect of the gas.

These results nevertheless are not sufficient for an accurate calculation of the Ak values. More suited for this purpose are the experiments in greenhouses where the CO_2 concentration throughout the vegetation period can be held more constant than in the field.

Glasshouse experiments with cucumbers, tomatoes, beans, and sugar beets were carried out during 1921 to 1923 and in 1925. The carbon dioxide con-

TABLE 7

Results of CO_2 fertilization in the field

BEETS, 1922	FULL MINERAL FERTILIZER	FULL MINERAL FERTILIZER + CARBON DIOXIDE FROM MANURE IN ASPHALTED FELT BETWEEN THE ROWS	INCREASE IN THE PLOTS RECEIVING CO_2
			per cent
Average yield of roots	379.4 kgm.	451.2 kgm.	19
BEETS, 1923	**FULL MINERAL FERTILIZER**	**FULL MINERAL FERTILIZER + 40 KGM. PURE CARBON DIOXIDE FROM STEEL FLASKS**	**INCREASE IN THE PLOTS RECEIVING CO_2**
			per cent
Average yield of roots	369.6 kgm.	419.0 kgm.	16
CO_2 concentration in the air among the leaves*	0.520 mgm. per liter	0.600 mgm. per liter	14.5
OATS, 1923	**MINERAL FERTILIZER**	**MINERAL FERTILIZER 20 KGM. CARBON DIOXIDE FROM JULY 28 TO AUGUST 17**	**INCREASE IN THE PLOTS RECEIVING CO_2**
			per cent
Average yield, green	46.0 kgm.	60.0 kgm.	30.5
CO_2 concentration among the leaves*	0.517 mgm. per liter	1.088 mgm. per liter during the gassing	

* Average from daily analyses in the field.

N. B. Attention is called to the first experiment where manure was used as a source of CO_2. The manure was isolated from the soil by asphalted felt, placed in furrows dug between the rows of plants (fig. 12). This experiment proves that the carbon dioxide evolved from decomposing organic matter has the same effect as carbon dioxide produced from inorganic sources.

centration in the gassed house and in the control house was determined by analyses once or twice a day. The two houses were otherwise uniformly treated. The results of the experiments with cucumbers are given in table 8, and with sugar beets, in table 9.

These experiments indicate Ak values of 1.45 to 1.67, for cucumber, of 1.20 to 1.28 for sugar beets. Approximative calculations for the field experiments cited above give Ak values of about 0.60 to 0.75. The difference is probably

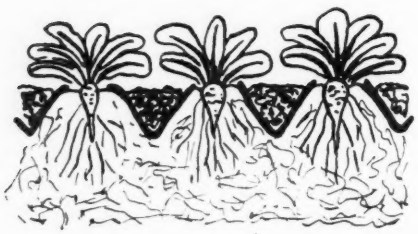


FIG. 12. ARRANGEMENT FOR GASSING OF BEETS WITH CARBON DIOXIDE EVOLVED FROM MANURE

The manure, mixed with soil, is put into furrows that are coated with asphalted felt and is consequently isolated from the soil. The carbon dioxide produced from it escapes into the atmosphere and enriches the air among the plant leaves.

due to the fact that Ak for the carbohydrate assimilation increases with temperatures up to 30°C. The temperature in the glasshouses was in general of the latter order, whereas the temperature in the field averaged 12 to 20°C. (see table 5).

TABLE 8

Cucumbers in glasshouses

	YIELD OF	GASSED HOUSE	CONTROL	INCREASE
				per cent
1922	Cucumbers	150.92 kgm.	100.49 kgm.	50
	Average CO_2 concentration	0.044 volume per cent	0.034 volume per cent	30
1923	Cucumbers	25.879 kgm.	15.187 kgm.	74
	Average CO_2 concentration	0.065 volume per cent	0.043 volume per cent	51

TABLE 9

*Sugar beets in glasshouses**

1925	HOUSE 1	HOUSE 2	HOUSE 3
	gm.	*gm.*	*gm.*
Average yield, absolute (*roots*)	794	1148	1211
Average yield, relative (*roots*)	100	145	152
	mgm. per liter	*mgm. per liter*	*mgm. per liter*
Average CO_2 concentration, absolute	0.6806	0.7705	0.8652
Average CO_2 concentration, relative	100	113.2	127.1
	gm.	*gm.*	*gm.*
Average yield, absolute (*leaves*)	908	1195	1428
Average yield, relative (*leaves*)	100	132	157

* The plants were cultivated in vessels each containing about 30 liters of soil, 7 plants in each house.

Soil respiration as the source of atmospheric CO_2

The total carbon dioxide evolution from the soil attains very high values. The author's investigations demonstrate values from 1.25 to 13.6 kgm. CO_2 per hectare per hour or 0.63 to 6.4 million liters in 90 days. The highest values refer of course to heavily fertilized soils, but forest soils also often attain as high values. In comparison, mention might be made that a growing field of oats consumes about 10,000 kgm. (2 million liters CO_2) in the vegetation period. The soil, therefore, frequently is producing as much carbon dioxide as the crop is using, a fact that can be generalized for the whole earth, because the living organisms after death, as a rule are completely decomposed. It is only in peats and in such deposits as charcoal that non-decomposed organic matter is stored up.

The total amount of carbon dioxide in the atmosphere is estimated at about 2100 billion kgm. (31). Growing plants take yearly about one-thirty-fifth

TABLE 10

Variations in free atmosphere during the summer period

	1920	1921	1922	1923	1924
CO_2 content..... *mgm. per liter*	0.612	0.5603	0.5267	0.5565	0.6189
CO_2 content..... *per cent of volume*	0.03295	0.03031	0.02843	0.0300	0.0331
Temperature.....°C.	19.1	17.3	16.5	15.4	16.4
Maximum variation.....*per cent*	75.6	90.0	108.9	77.6	60.4
Mean variation.....*per cent*	.....	±16.1	±15.2	±14.4	±21.0

of this quantity, and about the same amount is restored by soil respiration. As the assimilation and the soil respiration do not vary according to the climatic factors, variations must be expected in the average percentage of carbon dioxide of the free atmosphere from year to year and also from season to season. Levy has shown such variations at Montsouris. The author's observations in the summer period at the Station of Hallands Väderö for the free atmosphere near the sea level gave the averages shown in table 10.

It cannot be assumed therefore that the amount of carbon dioxide in the atmosphere is constant. It varies from year to year up to 16.6 per cent (cf. 1922 and 1924) and considerably from day to day. As stated in a previous paper, the variations are related to climatic conditions, especially light and rainfall, that influence the assimilation or the soil respiration (17).

In order to measure more accurately the concentration of the carbon dioxide among the plant leaves, which of course is the real carbon dioxide factor of assimilation and growth, extensive series of analyses were made in the years 1921 to 1925. For the analyses the author used a new apparatus, consisting

of a gas-holder, in which about 2.3 liters of air stands for several hours over a free surface of diluted baryta solution (fig. 13). The baryta from which free air is excluded is then drawn off into small flasks that are transported to the laboratory and titrated. From 10 to 14 such apparatuses are left standing in the field, protected from the weather by a wooden cupboard (fig. 14). The air sample is drawn through a glass tube about 5 m. long and 3 mm. in diameter,

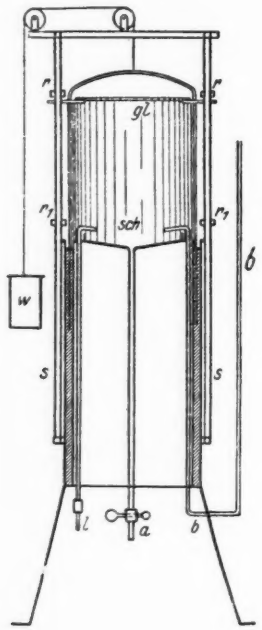


FIG. 13. APPARATUS FOR ANALYZING THE CARBON DIOXIDE CONTENT IN THE FIELD

A metal bell is suspended in glycerine. The air sample is drawn through the tube *l* by applying the weight *W*. The volume is determined by the offsets *rr* and r_1r_1. When the sample is taken, baryta solution is poured into the bowl *sch* through *bb*. After a few hours the baryta solution from which free air is excluded is poured out through *a* into a small flask and then titrated with 0.025 *N* HCl.

from close to the assimilating plants (fig. 14). This apparatus is working very satisfactorily, with an error of only about ±0.005 mgm. CO_2 per liter air or ±0.0003 per cent of volume for single observations. Thus even very small variations in the CO_2 factor can be traced. In plate 1, figures 2 and 3, is shown the field laboratory, where the chemical work is done.

The results from 1921 to 1923 are exhaustively dealt with in a previous paper (17). A few results are shown in tables 4, 5, and 10 and in figures 7 and 8.

The tables and the figures show rather clearly that the variations in the CO_2 concentration among the leaves and even in the free atmosphere above the plants are related to corresponding variations in the soil respiration. The

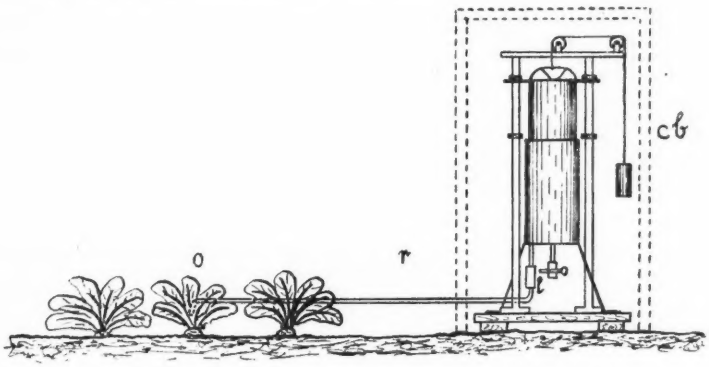


FIG. 14. ARRANGEMENT FOR SECURING THE AIR SAMPLES IN THE FIELD

cb, the apparatus (see fig. 13) protected under a cupboard; *r*, a 5 m. long, narrow glass tube, the end of which (*O*) is bent down among the leaves.

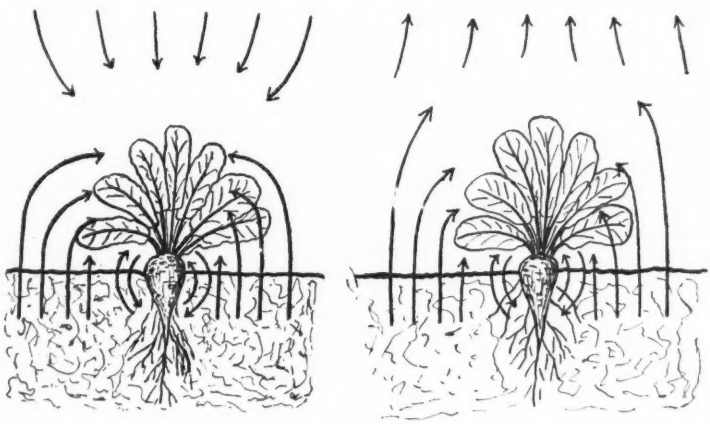


FIG. 15 FIG. 16

FIG. 15. DIAGRAM OF THE DIFFUSION CURRENTS WHEN THE CARBON DIOXIDE FACTOR IS BELOW THE STANDARD VALUE

FIG. 16. DIAGRAM OF THE DIFFUSION CURRENTS WHEN THE CARBON DIOXIDE FACTOR EXCEEDS THE STANDARD VALUE

correlation is very impressive, if plots of the same field receive different fertilizer treatments. When the soil respiration is stimulated by applications of mineral fertilizers (cf. p. 430), the CO_2 concentration among the leaves

in most cases will be raised too. With beets that are growing rapidly, however, the CO_2 factor may be decreased, because the rapidly growing leaves are absorbing more carbon dioxide than the soil can produce.

In studying the relations between the intensity of soil respiration and the intensity of the CO_2 factor in the level of the assimilating leaves, there is one point of special interest that throws light upon the important problem of diffusion in the atmosphere.

As long as the CO_2 factor is lower than the CO_2 concentration in the free air (*"standard value,"* measured simultaneously 5 m. above the ground), there will be a diffusion of carbon dioxide downward, as illustrated by the arrows in figure 15. All carbon dioxide that comes from the soil will in this case be absorbed by the plants.

When the CO_2 factor exceeds the standard value, there will be a diffusion stream from the level of the leaves up to the free atmosphere (see the arrows in fig. 16); part of the carbon dioxide evolved from the soil in this case will escape between the leaves and disappear into the free atmosphere.

Table 11 shows between the soil respiration and the CO_2 factor a strikingly constant ratio until the standard value is reached by the CO_2 factor. The ratio suddenly rises in the two first series. In the third series with oats (1923) no such rise is observed. In the fourth series with sugar beets (1925) the standard value had already been attained in the plots that had received no fertilizer, but here too, the ratio rises with the increasing CO_2 factor.

From the fact stated in table 11 that a distinct relation prevails between soil respiration and the CO_2 factor in the level of the assimilating leaves, it must be concluded that the CO_2 factor and, thus, the carbohydrate assimilation of the plants are essentially regulated by the carbon dioxide evolution from the soil under the plants. The soil respiration is equal to the assimilation (cf. p. 437), and while this carbon-source for the leaves is the nearest it is the dominating one. Carbon dioxide is of course taken up from the free atmosphere too, but not to any very great extent, especially when the CO_2 factor is higher than the standard value. If the soil respiration fails to furnish a sufficient quantity of CO_2, the supply from the atmosphere (cf. fig. 15) is furnished too slowly to prevent a CO_2 deficit among the leaves and thus a partial starving.

The plants are more or less isolated from the higher strata in the atmosphere and the circulation of the carbon in nature is most rapid in the ground stratum. This is dependent upon the fact that not diffusion but convection currents are the chief mode of carbon dioxide dissemination, and that these currents (winds) move in horizontal rather than in vertical directions. Furthermore the friction is very high among the plants. The difference between the CO_2 factor and the standard value is diminished when the weather is very windy, but is seldom eliminated. The mean difference in the vegetation period is considerable even on bleak places (17, p. 256) when a discrepancy between soil respiration and assimilation prevails.

The conclusions drawn in this paper are based upon continuous observations

at 42 points on differently treated plots in crop fields and at several points in the forest. During the vegetation period from each point were made series of daily observations of the carbon dioxide concentration, light intensity, rainfall, humidity, temperature, atmospheric pressure, wind velocity, and wind direc-

TABLE 11

Reaction between soil respiration and CO_2 factor

First series—Oats, 1921

	INCREASING FERTILIZATION				
	1	2	3	4	5
Soil respiration.....*gm.* per sq. m. per hour	0.348	0.372	0.408	0.417	0.572
CO_2 factor (standard value = 0.026).....*per cent*	0.0216	0.022	0.0249	0.0274	0.0284
Ratio.....	16:1	17:1	16:1	15:1	20:1

Second Series—Cabbage, 1921

	INCREASING FERTILIZATION			
	1	2	3	4
Soil respiration.....*gm.* per sq. m. per hour	0.224	0.273	0.284	0.590
CO_2 factor (standard value = 0.0335).....*per cent*	0.0305	0.0316	0.0346	0.0365
Ratio.....	14:1	12:1	12:1	16:1

Third series—Oats, 1923

	INCREASING FERTILIZATION		
	1	2	3
Soil respiration.....*gm.* per sq. m. per hour	0.291	0.404	0.521
CO_2 factor (standard value = 0.0290).....*per cent*	0.0186	0.0244	0.0358
Ratio.....	16:1	16:1	15:1

Fourth series—Sugar beets, 1925

	INCREASING FERTILIZATION				
	1	2	3	4	5
Soil respiration.....*gm.* per sq. m. per hour	0.200	0.270	0.264	0.290	0.324
CO_2 factor (standard value = 0.0331).....*per cent*	0.0334	0.0340	0.0336	0.0345	0.0348
Ratio.....	6:1	8:1	7.9:1	8.4:1	9.3:1

All values are means from series.

tion. Special series deal with the changes in the carbon dioxide concentration from noon to afternoon and night, and the distribution of the gas at different heights above the soil surface up to the top leaves and the free air. Only a few of the chief results have been reported here.

TABLE 12

Extract of the results concerning mean values of the CO_2 factor

		MAXIMUM	MINIMUM	MEAN AND STANDARD DEVIATION		RELATIVE VALUE
		mgm.	*mgm.*	ϵ *mgm.*	σ *mgm.*	
1921	*Free air*	0.76	0.40	0.560 ±0.0126	±0.090	100.0
	Potatoes, weak fertilizer	1.04	0.25	0.542 ±0.023	±0.161	90.0
	Cabbage, weak fertilizer	1.01	0.30	0.568 ±0.016	±0.109	95.3
	Cabbage, heavy fertilizer	1.34	0.42	0.680 ±0.029	±0.207	112.7
1922	*Free air*	0.71	0.34	0.527 ±0.008	±0.080	100.0
	Oats, no fertilizer	0.63	0.11	0.408 ±0.018	±0.126	77.4
	Oats, fertilized	0.81	0.30	0.541 ±0.014	±0.100	102.7
	Potatoes, no fertilizer	0.74	0.10	0.308 ±0.019	±0.112	58.3
	Potatoes, fertilized	0.85	0.10	0.364 ±0.039	±0.200	69.0
1923	*Free air*	0.71	0.47	0.556 ±0.007	±0.080	100.0
	Oats, no fertilizer	0.97	0.12	0.344 ±0.040	±0.240	61.9
	Oats, fertilized	1.17	0.35	0.662 ±0.039	±0.204	119.1
	Potatoes, no fertilizer	1.07	0.11	0.511 ±0.045	±0.270	92.9
	Potatoes, fertilized	1.67	0.60	0.661 ±0.047	±0.294	120.2

N. B. The oats (1922 and 1923) were fertilized with 300 kgm. manure to each 100 sq. m. + superphosphate, potassium chloride, and sodium nitrate, 3 kgm. to the 100 sq. m. The potatoes were fertilized with 300 kgm. manure and 2 kgm. superphosphate, 1.5 kgm. potassium chloride, and 2 kgm. sodium nitrate. The sugar beets were fertilized with 4 kgm. each of superphosphate, potassium chloride, and sodium nitrate. All plots were fertilized in the spring.

TABLE 12—*Continued*

		MAXIMUM	MINIMUM	MEAN AND STANDARD DEVIATION		RELATIVE VALUE
		mgm.	*mgm.*	ϵ *mgm.*	σ *mgm.*	
1925	*Free air*	0.876	0.425	0.6163 ±0.004	±0.041	100.0
	Sugar beets, no fertilizer	1.032	0.443	0.6215 ±0.022	±0.242	100.8
	Sugar beets, 400 kgm. manure	0.989	0.314	0.6304 ±0.010	±0.111	100.4
	Sugar beets, mineral fertilizer, + 400 kgm. manure	0.979	0.422	0.6459 ±0.011	±0.121	106.95

Soil respiration and fertility

It has been shown that: 1. Fertilization as a rule raises the soil respiration; 2. The CO_2 factor is largely dependent upon the soil respiration; and 3. The CO_2 factor is an important growth-factor. Thus fertilization of the soil will serve as an indirect CO_2 fertilizer (table 12).

The experiments have shown that over soils that have received no manure or fertilizer the CO_2 factor as a rule is lower than the standard value. For comparison, the latter is marked 100.0 (table 12, last column). This is the normal value of the CO_2 factor, but (to repeat) is frequently not attained over unfertilized soils where the soil respiration is not sufficient for the needs of assimilation, especially where the plants are standing close together, so that the air circulation slackens. On the same soil, therefore, oats show the lowest CO_2 factor, then potatoes; whereas beets, especially sugar beets (table 12), will permit sufficient air circulation to maintain a rather normal CO_2 factor even over unfertilized soils (17, p. 248).

Fertilization will increase the CO_2 factor more or less up to the standard value. According to figures 15, 16 and the discussion above, the CO_2 factor will rise more easily up to 100 than over 100.

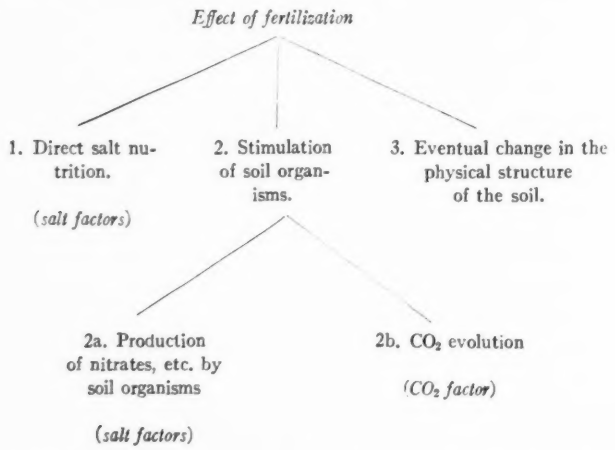
There is another fact that must be kept in mind in discussing the problem of indirect CO_2 fertilization. The fertilizer not only stimulates the microbiological activity in the soil but also acts directly as nutrition for the higher plants. This direct action is the only one to which attention has hitherto been paid in agriculture.

The growth of the plant is controlled by a number of growth factors, including carbon dioxide and the nutrient salts, the carbon dioxide very often controlling the yield. For the full utilization of the carbon dioxide, of course, a sufficient supply of nutrient salts is necessary. When the concentration of the salts on the other hand is too high, a retarding effect may result and this again will reduce the effect of the CO_2 factor. From this viewpoint a too heavy manuring or fertilizing, although it highly favors the soil respiration, is to be regarded as impractical. Only certain vegetables seem to endure very high quantities of

manure, and on the other hand it is a well known fact that beets require abundant salts.

There is another limit for the indirect CO_2 fertilization. It has been stated that the lower limit for the injurious effect of CO_2 accumulation in the pore space of the soil is about 1 per cent 15 cm. below the soil surface. When the CO_2 evolution is stimulated without provision for facilitating the aeration, the CO_2 concentration in the soil increases and finally the 1 per cent limit is attained and surpassed. As the normal concentration in 15 cm. depth reaches about 0.3 per cent, there is a broad margin for fertilization. Many plants endure CO_2 concentrations above 1 per cent.

The total effect of manure and mineral fertilizers is thus always split up into two chief components: first, the direct salt action upon the higher plants (salt factors), and, second, the indirect salt action (CO_2 factor), i.e., the stimulating effect upon the microörganisms. But these two chief actions are to a certain extent interwoven, for with stimulation of the soil activity, more nitrates etc. are produced (see following scheme).


Effect of fertilization
1. Direct salt nutrition.
(salt factors)
2. Stimulation of soil organisms.
3. Eventual change in the physical structure of the soil.
2a. Production of nitrates, etc. by soil organisms
(salt factors)
2b. CO_2 evolution
(CO_2 factor)

On account of the circumstances mentioned, there will be in general a certain parallelism between soil respiration and crop yield, with fertilization experiments on the same soil. The soil respirations of different soils do not stand in any simple relation to the fertility: for example, a clay soil of low respiration may be more fertile than a sandy humus soil of high respiration (table 11). The microbiological population and the salt content of these two types of soils are too different to permit the use of the respiration as an indicator of the total fertility.

Figures 17 and 18 demonstrate a striking parallellism between soil respiration and yield. To what extent is the increase in yield due to the carbon dioxide factor? If we know the quotient Ak (p. 434), the part which the CO_2 factor

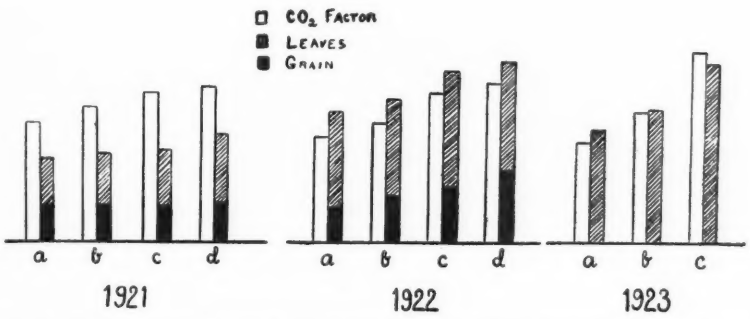


FIG. 17. DIAGRAM SHOWING THE PARALLELISM BETWEEN CARBON DIOXIDE FACTOR AND THE YIELD OF OATS

a = no manure, *b* = farmyard manure, *c* = mineral fertilizer, *d* = mineral fertilizer + manure.

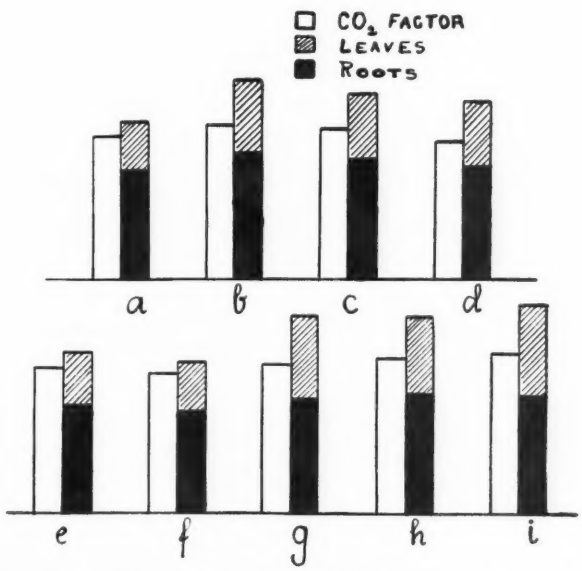


FIG. 18. DIAGRAM SHOWING THE PARALLELISM BETWEEN CARBON DIOXIDE FACTOR AND YIELD OF SUGAR BEETS

a-d = increasing intensities of hacking, *e* = no manure, *f* = farmyard manure, *g* = mineral fertilizer, *h* and *i* = mineral fertilizer + manure.

alone plays can be calculated. As already stated further experiments are necessary for estimating accurate values of Ak. It will probably develop that Ak varies also with the salt nutrition. Starting with Ak as low as 0.60

TABLE 13

Carbon dioxide factor and yield

Oats, 1921

	(a) 300 KGM. MANURE HACKING	(b) 300 KGM. MANURE	(c) 400 KGM. MANURE	(d) 3 KGM. SUPERPHOSPHATE, 6 KGM. POTASSIUM CHLORIDE, 4 KGM. SODIUM NITRATE
CO_2 factor.....*mgm.*	0.413 ±0.028	0.466 ±0.047	0.512 ±0.040	0.534 ±0.052
CO_2 relative value	77.7	99.9	108.7	113.4
Yield Seeds.....*kgm.*	12.5	12.5	12.07	13.17
Yield Straw.....*kgm.*	16.0	17.75	19.76	21.16
S:a.....*kgm.*	28.50 ±1.10	30.25 ±0.60	31.83 ±0.88	35.33 ±1.05

Oats, 1922

	(a) NO MANURE	(b) 300 KGM. MANURE	(c) 3 KGM. SUPERPHOSPHATE, 3 KGM. POTASSIUM CHLORIDE, 3 KGM. SODIUM NITRATE	(d) 3 KGM. SUPERPHOSPHATE, 3 KGM. POTASSIUM CHLORIDE, 3 KGM. SODIUM NITRATE, 300 KGM. MANURE
CO_2 factor.....*mgm.*	0.363 ±0.019	0.408 ±0.018	0.506 ±0.019	0.543 ±0.014
CO_2 relative value	68.5	75.6	94.2	101.3
Yield Seeds.....*kgm.*	31	32	42	43
Yield Straw.....*kgm.*	11	16	20	23
S:a.....*kgm.*	42 ±1.68	48 ±2.45	62 ±2.50	66 ±2.51

Oats, 1923

	(a) NO MANURE	(b) 3 KGM. SUPERPHOSPHATE, 3 KGM. POTASSIUM CHLORIDE, 3 KGM. SODIUM NITRATE	(c) 3 KGM. SUPERPHOSPHATE, 3 KGM. POTASSIUM CHLORIDE, 3 KGM. SODIUM NITRATE, 300 KGM. MANURE
CO_2 factor.....*mgm.*	0.344 ±0.040	0.452 ±0.034	0.662 ±0.039
CO_2 relative value	1.9	81.3	119.1
Yield (total).....*kgm.*	58.5 ±2.50	76.5 ±0.88	93.8 ±1.25

TABLE 13—*continued*

Sugar beets, 1925*

	(a) HACKING FOUR TIMES 5/22/5 TO 6/27/6	(b) HACKING SIX TIMES 5/22/5 TO 6/29/6	(d) HACKING THIRTEEN TIMES 5/22/5 TO 8/26/6
CO_2 factor.....*mgm.*	0.6591	0.6398	0.5826
CO_2 relative value	107.0	103.8	94.5
Yield roots†.....*kgm.*	219	206	191
Yield relative value	107.0	101.0	93.0
Yield leaves.....*kgm.*	124	117	115
S:a.....*kgm.*	343	323	306
	107.0	101.0	95.5
Ratio, roots : leaves	1.77	1.76	1.66

	(e) NO MANURE	(f) 400 KGM. MANURE	(g) 4 KGM. SUPERPHOSPHATE, 4 KGM. POTASSIUM CHLORIDE, 4 KGM. SODIUM NITRATE	(h) 4 KGM. SUPERPHOSPHATE, 4 KGM. POTASSIUM CHLORIDE, 4 KGM. SODIUM NITRATE, 200 KGM. MANURE	(i) 4 KGM. SUPERPHOSPHATE, 4 KGM. POTASSIUM CHLORIDE, 4 KGM. SODIUM NITRATE, 400 KGM. MANURE
CO_2 factor.....*mgm.*	0.6130	0.6081	0.6204	0.6414	0.6539
CO_2 relative value	100.0	99.6	101.1	104.9	106.95
Yield roots†.....*kgm.*	187	178	195	203	200
Yield roots relative value	100.0	95.0	104.3	108.6	107.0
Yield leaves.....*kgm.*	88	88	141	139	155
Total.....*kgm.*	275	266	336	342	355
	±15.6	±5.7	±6.4	±3.3	±5.9
Total relative value	100.0	96.7	122.3	124.3	129.0
Ratio, roots : leaves.....	1.59	1.73	1.28	1.34	1.29

* Plots a, b, and d fertilized with 3 kgm. superphosphate, 3 kgm. potassium chloride, 3 kgm. sodium nitrate to 100 square meters.

† To each 50 sq. m.

(p. 435) we nevertheless will find that in the case of oats the CO_2 factor constitutes 50 per cent or more of the total fertilizing effect (17, p. 278). In other cases, as for example sugar beets in 1925, the increase in yield due to the carbon dioxide is smaller in comparison to the high "salt effect." In plots *a*, *b*, *d* and where only the carbon dioxide factor was varied, the yield depends wholly upon it (table 13). In plot *g*, having the same carbon dioxide factor as plot *e* but received mineral salts, the yield increased 22.3 per cent. When by the addition of manure, the carbon dioxide factor is raised to 106.95, the

yield will rise in the same proportion, that is from 122.3 to 129.0. No doubt if it were possible to raise the carbon dioxide factor still more the yield would be correspondingly higher (table 9).

The soils in the oat experiments and in the sugar beet experiments were of a quite different quality. The former was a sandy loam rich in humus but poor in salts, the latter was a heavy clay soil not very rich in humus but rather fertile. Fertilizing with mineral salts, therefore, in the sandy loam will highly stimulate the carbon dioxide evolution and maintain a high CO_2 factor (see table 6 where an increase in carbon dioxide evolution up to 357 per cent is demonstrated). In the clay soil, the humus content probably limits the CO_2 evolution and the CO_2 factor, whereas the salt allows free development. The results indicate the importance of separating the two chief effects of fertilization according to the scheme on page 444.

For estimating the carbon dioxide factor that controls the plant growth, the direct analysis of the atmosphere among the assimilating leaves is accurate.[2] The measuring of the soil respiration serves well for comparing the effects of different treatments of the soil upon the carbon dioxide factor, but as the assimilation and the movements of the air among the leaves vary with the plants only the direct determination can indicate something about the prevailing CO_2 deficit or excess and the demands for fertilizing with this gas. It is obvious too that the CO_2 factor behaves differently from the salt factors with the variations of climate. The carbon dioxide is, for example dissipated by winds whereas the salts are washed out by rain. No two identical soils will therefore give the same yield, if the wind exposition is different.

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[2] As the CO_2 concentration is not the same at the level of the upper leaves as among the basal leaves, determinations from the middle of the leaf mass will give only an average, which, nevertheless, is sufficient for our purpose. It would be a very difficult task to make single determinations for each leaf, and such detailed work has no great value since the light factor varies from leaf to leaf. Moreover, the drawing of a 2.3 liter sample in a few minutes will give a very good idea of the average concentration among the whole leaf mass, when this is not too extended in vertical direction.

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PLATE 1

FIG. 1. Arrangement for determination of the Soil Respiration. To the left, the "respiration bell;" to the right, portable apparatus for CO_2 determination; connected by a rubber tube.

FIG. 2. The experiment field in 1925 with field laboratory and apparatuses for CO_2 determination, one on each plot.

FIG. 3. Interior of the field laboratory, showing the analysis apparatus at the left, the portable apparatus and respiration bell at the right.

FIG. 1

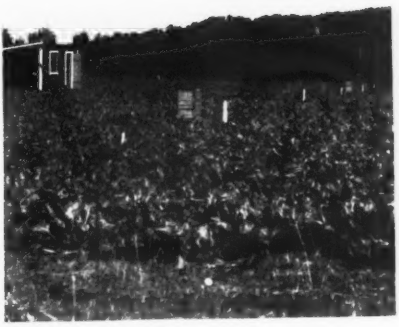

FIG. 2

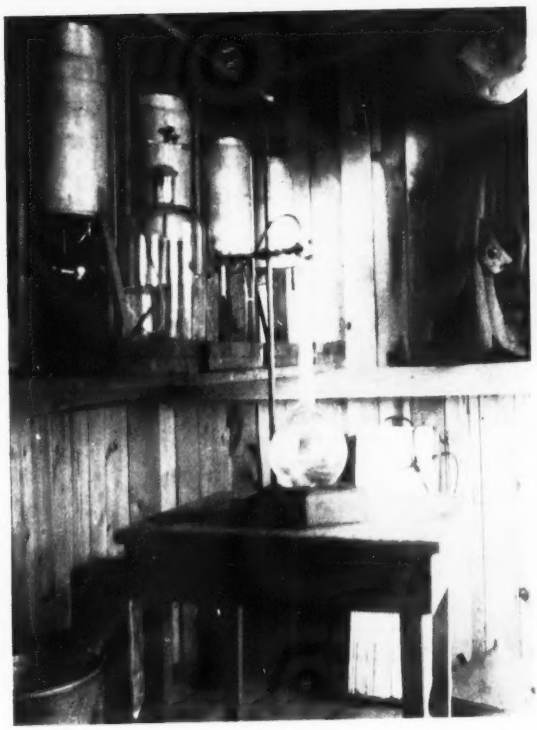

FIG. 3

PLATE 2

FIGS. 1 AND 2. Sugar beets from the non-gassed glasshouse 1. Carbon dioxide concentration 0.6806 mgm. to each liter of air.

FIGS. 3 AND 4. Sugar beets from the gassed house 2. Carbon dioxide concentration 0.7705 mgm. to each liter of air.

FIG. 2

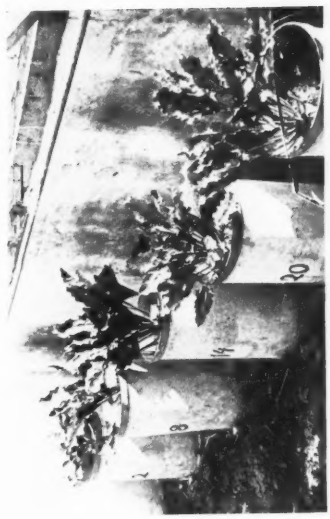

FIG. 4

FIG. 1

FIG. 3

UNIV. OF MICH.

THE SEEDLING PLANT METHOD OF DETERMINING SOIL NUTRIENT DEFICIENCY

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Since the beginning of agricultural research, the problem of determining plant nutrient deficiencies in the soil has been of major importance. Various methods of solving this problem have been proposed, including a complete analysis of the soil, extraction by acids of various kinds and strengths as well as by physiological means. It must be admitted, however, that at the present time there is no known method which is both accurate and generally adaptable.

During recent years, the use of growing plants as a means of obtaining indications of nutrient availability has received rather wide attention, to some extent in this country, but more extensively in continental Europe.

Mitscherlich (14) in Germany, has proposed a method of pot culture, involving the additions of complete fertilizers and of fertilizers deficient in the element under investigation. He has evolved a mathematical equation which when applied to field and pot yields is believed to indicate the deficiency of any given nutrient.

Holben and Haley (11) at the Pennsylvania Station, working with buckwheat plants, found some correlation between acid-soluble potash of the soil and potash removed by the plant.

Hoffer (10) of the Indiana Station has recently reported a method of analyzing the corn plant, both micro and macrochemically, which he claims gives an indication of the supply of nitrates and available potash in the soil.

The biological method of soil analysis proposed by Neubauer (15, 16) has been rather thoroughly investigated abroad, and has received some attention in this country, particularly by the sugar industry (6, 17). This method has been previously described by the authors (1).

As several foreign investigators (2, 4, 5, 12, 13, 18, 19) have reported upon the practical application of the seedling plant method for determining the nutritive requirements of the soil, it seemed advisable to investigate the practical application of this method as an indicator of the fertility requirements of soils in this country.

EXPERIMENTAL

As previously reported (1) it was found necessary to modify the original Neubauer procedure. Hahne (8, 9) has also found modification essential to good results.

It was found advisable to use larger pots of 12½ cm. diameter and 7 cm. depth mainly to give sufficient area to prevent undue crowding of the seedlings. A dilution of 200 gm. of soil and 1000 gm. sand was found to give best results. As the results with rye were unsatisfactory, wheat and several other plants, including corn, buckwheat, and soybeans have been tried.

For satisfactory results in a test of this kind it is necessary to choose seed with a high percentage of germination and uniformity in composition, for it is essential that the seedlings make an even and rapid growth.

Soils from the 5-year rotation experiment of the Ohio Agricultural Experiment Station at Wooster were used in this series of tests. A few sandy soils from the Lake Erie district were also included for comparison, since these sandy soils are commonly considered to be deficient in potassium.

Series 1 consists of plot soils that have received various combinations of fertilizers. As the soils of these plots have been under regular treatment for a period of 30 years, it would be expected that some would be markedly deficient in the element or elements not included in the fertilizer treatment received.

The selected wheat seeds, previously treated with "Upsulun," a chlorphenol mercury compound, were planted, 100 to a pot, in the soil previously made up as above and brought to optimum moisture content. At the end of 18 days the tops and roots were harvested separately and analyzed for phosphorus and potassium.

The object of making a separate analysis of the roots, rather than using the whole plant, as Neubauer and others have done, was to determine whether the tops are as good indicators of nutrient availability as the whole plant, since if they should be, the error due to inability thoroughly to remove the soil from the roots, and to secure all the roots in the pot would be avoided.

The data presented in tables 1 and 5 indicate that it is unnecessary to analyze the roots. The potassium assimilation by the tops has in every case paralleled the assimilation by the whole plant.

Comparison of potassium and phosphorous assimilation by pot and field samples

The wheat series were planted in pots late in September on the same date that the wheat was sown in the field. At the end of 18 days when the pots were harvested, representative samples from each field plot were also harvested and analyzed for potassium and phosphorous. By growing the pot series through the same period of time it was hoped to eliminate as far as possible certain errors between field and pot samples, particularly photo-periodic effects. The analyses of the field samples were calculated to the same weight as the plants in the pot test. As shown in table 2, representing soils of the 5-year rotation, and table 6, representing soils of the 3-year rotation (20), the potassium assimilated in pot culture varied directly with that assimilated in the field in every case excepting plot 11 of the 5-year rotation. This is the complete fertilizer plot. Apparently the pot cultures are fair indicators of field conditions,

TABLE 1

Relative value of wheat tops, roots, and total plant material as indicators of potassium and phosphorous absorption

(Soils from 5-year rotation)

PLOT NUMBER	TREATMENT	WEIGHT OF PLANTS			POTASSIUM ABSORBED			PHOSPHORUS ABSORBED		
		Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
		gm.	*gm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
	Pure sand	0.954	1.648	2.602	7.35	6.55	13.90	9.40	7.38	16.78
2	P_2O_5	1.162	1.543	2.705	10.85	7.07	17.92	9.74	6.47	16.21
3	KCl	1.219	1.605	2.824	14.11	8.64	22.75	9.94	6.57	16.41
5	$NaNO_3$	1.122	1.472	2.594	10.24	7.77	18.01	9.54	6.77	16.31
6	$P_2O_5 + NaNO_3$	1.160	1.510	2.660	11.25	7.43	18.68	8.86	6.77	15.63
8	$KCl + P_2O_5$	1.155	1.409	2.564	14.31	10.41	24.72	8.99	6.16	15.15
9	$KCl + NaNO_3$	1.207	1.460	2.667	12.75	8.72	21.49	9.03	7.24	16.27
11	$KCl + NaNO_3 + P_2O_5$	1.198	1.499	2.697	11.70	7.75	19.45	8.36	8.73	17.09

TABLE 2

Comparison of wheat yield and acid-soluble potassium with the available potassium by the Neubauer test and that present in field samples—tops only used as indicators

(Soils from 5-year rotation, Wooster)

PLOT NUMBER	WHEAT YIELD	ACID-SOLUBLE K	AVAILABLE K BY NEUBAUER TEST	K IN FIELD SAMPLE
	bu.	*p.p.m.*	*mgm.*	*mgm.*
2	22.0	17	10.85	18.49
3	14.88	36	14.11	26.72
5	14.30	23	10.24	14.15
6	25.88	17	11.25	13.72
8	24.49	30	14.31	23.09
9	15.32	32	12.75	21.56
11	30.33	31	11.70	28.10

Field samples based on same weight as 100 plants from pot tests.

TABLE 3

Comparison of phosphorus extraction by "Neubauer method" with actual assimilation in the field and the yield of wheat

(Soils from 5-year rotation, Wooster)

TEST	PLOT 2	PLOT 3	PLOT 5	PLOT 6	PLOT 8	PLOT 9	PLOT 11
Neubauer method, *mgm.*	9.74	9.94	9.54	8.86	8.99	9.03	8.36
Field sample, *mgm.*	8.26	6.47	5.56	6.74	7.35	4.68	7.43
Wheat yield, *bu.*	22.0	14.88	14.30	25.88	24.49	15.32	30.33

Field samples based on weight of 100 plants in pot test.

TABLE 4

Comparison of phosphorus extraction by "Neubauer method" with actual assimilation in the field

(Soils from 3-year rotation, Wooster)

TEST	PLOT 2	PLOT 3	PLOT 5	PLOT 6	PLOT 8	PLOT 9	PLOT 11
Neubauer method, *mgm.*	9.44	10.58	9.27	7.75	8.08	8.63	7.48
Field sample, *mgm.*	7.41	6.32	5.87	6.10	7.50	4.90	6.86
Wheat yield, *bu.*	34.82	28.61	27.84	34.74	35.97	30.13	36.82

TABLE 5

Relative value of tops, roots, and total plant material as indicators of potassium and phosphorus absorption

(Soils from 3-year rotation)

PLOT NUMBER	TREATMENT	WEIGHT OF PLANTS			POTASSIUM ABSORBED			PHOSPHORUS ABSORBED		
		Tops	Roots	Total	Tops	Roots	Total	Tops	Roots	Total
		gm.	*gm.*	*gm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*	*mgm.*
	Pure sand	1.033	1.531	2.564	6.23	7.91	14.14	8.76	8.19	16.95
2	P_2O_5	1.061	1.413	2.474	9.20	9.08	18.28	9.44	8.09	17.53
3	KCl	1.305	1.364	2.669	16.56	10.72	27.28	10.58	8.52	19.10
5	$NaNO_3$ + dried blood	1.173	1.539	2.712	9.76	8.88	18.64	9.27	8.73	18.00
6	$NaNO_3 + P_2O_5$ + dried blood	1.127	1.570	2.697	8.92	9.96	17.88	7.75	6.53	14.28
8	P_2O_5 + KCl	1.254	1.532	2.786	14.39	9.12	23.51	8.08	5.62	13.70
9	$NaNO_3$ + KCl + dried blood	1.219	1.539	2.758	10.60	9.68	20.28	8.63	7.54	16.17
11	$NaNO_3 + P_2O_5$ + KCl + dried blood	1.061	1.442	2.503	8.48	8.68	17.16	7.48	6.81	13.29

TABLE 6

Comparison of wheat yield and acid-soluble potassium with the available potassium by Neubauer test and that present in field sample—tops only used as indicators

(Soils from 3-year rotation, Wooster)

PLOT NUMBER	WHEAT YIELD	ACID-SOLUBLE POTASSIUM	K BY NEUBAUER TEST	K IN FIELD SAMPLE
	bu.	*p.p.m.*	*mgm.*	*mgm.*
2	34.82	25	9.20	24.35
3	28.61	37	16.56	48.48
5	27.84	28	9.76	23.75
6	34.74	22	8.92	16.59
8	35.97	..	14.39	39.11
9	30.13	..	10.60	34.67
11	36.82	..	8.48	30.50

although plants grown in the field assimilated much greater quantities of potassium, probably because of the larger amount of soil at their disposal.

The converse is true of phosphorous assimilation, as shown in tables 3 and 4. In every case the field-grown plants contain less phosphorous than those of the pot cultures, and furthermore, the pot cultures are remarkably uniform in phosphorous assimilation, showing much less variation than the field samples. Apparently the pot cultures give little indication of field nutritional conditions so far as phosphorous is concerned.

Comparison of potash assimilation in pot culture with the soluble potash of the soil and with the wheat yield

There are wide differences in the centi-normal nitric-acid-soluble potassium in these soils as shown by Ames and Simon (2). A comparison of the potassium assimilated by wheat plants in pot culture with the acid-soluble potassium of the soil shows practically no correlation for the soils from plots of the 5-year

TABLE 7

Results of Neubauer test with wheat seedlings on Dunkirk and Maumee fine sands

SOIL	PREVIOUS TREATMENT	ACID-SOLUBLE K IN SOIL	POTASSIUM ABSORBED		
			Tops	Roots	Total
		p.p.m.	*mgm.*	*mgm.*	*mgm.*
Dunkirk fine sand	Virgin	36.27	11.21	8.20	19.41
Dunkirk fine sand	Cropped	53.10	11.94	8.68	20.62
Dunkirk fine sand	Potatoes, then pasture 15 years	32.78	10.20	8.65	18.85
Maumee fine sand	Virgin	14.48	12.58	7.47	20.05

rotation. In the case of the 3-year rotation fertility soils there appears to be some agreement for the first four plots, although the lack of acid-soluble figures for the last three soils of this series precludes drawing any definite conclusions.

Comparison of wheat yield with potash assimilated by wheat seedlings

A comparison of the average wheat yield for the last five years on these plots, with the available potassium as indicated by the seedlings, is given in tables 2 and 6. It is notable that plot 11 of both the 3 and 5-year rotations, gives the highest yield, as would be expected since these plots received a complete fertilizer treatment. The biologically available potassium on these plots, however, is much less than for plot 9 of both rotations, which received only nitrates and potash and produced a much lower average yield, whereas the assimilated potassium for plot 11 is but slightly greater than from plot 6 for both rotations, although the latter plot has never received any addition of potassium.

An explanation of this may be that the heavy yields of plot 11 have tended to utilize the available potassium to such an extent that there has been no ac-

cumulation in the soil. From the results for those plots which have never received potassium additions; namely, plots 2 and 6 of both rotations, it would appear that the yields have been so low that the supply of native potash becoming available in these soils has not been greatly reduced.

As a further check upon the reliability of this method, particularly the use of the wheat plant, a series was grown, using Dunkirk and Maumee fine sands from the Lake Erie district. A description of the soils with the results obtained is given in table 7.

Here again it is to be noted that the tops are better indicators of potassium availability than is the whole plant, since the tops exhibit considerable variability, whereas the roots are remarkably uniform in potassium content.

Although these sandy soils are considered to be naturally deficient in potassium, the assimilated potassium is in every case equal to, or more than, that from plots in the 5- and 3-year rotations which have received no potassium. The acid-extractable potassium is also remarkably high upon these soils and there is no correlation between the acid-soluble and the biologically available potassium.

Phosphorous availability

The data in tables 1, 3, 4, and 5, show that in no case is the variation in the phosphorous assimilation by the wheat seedlings of sufficient magnitude to indicate any variation in availability. In fact the data in tables 1 and 5 show that the phosphorous assimilated by the plants corresponds closely to the amount in the seed, the phosphorous content of plants in the sand checks being in most cases equal to or greater than that of plants grown on diluted soil. On the other hand, the phosphorous content of plants grown in the field varies as much as 3 or 4 mgm. among the different plots.

Studies with other plants

Although the variation in potassium assimilation indicates that the seedling test may have some value, the results for phosphorous show that the wheat plant can not be used as an indicator of the availability of this element. In order to determine whether other plants than wheat might have greater utility, three new series using corn, soybeans, and buckwheat were grown in soils from the same plots used for the wheat series.

These plants were grown 18 days and since results from wheat plants had indicated that it was unnecessary to utilize the roots, only the tops were harvested.

The buckwheat series proved of no value. The germination percentage was very low and extremely variable; the seedlings were very spindling and many cotyledons had dropped off, leaving only a bare, leafless stem by the eighteenth day.

The results of analyses of corn for potash and phosphorous are given in table 8. Although there is a considerable variation in the assimilated potas-

sium, there is no direct correlation with the acid-soluble potassium or yield of the plots other than that an increased yield seems to have greatly reduced the available potassium of the soil even with a considerable addition of potash salts. The reduction is greater than on soils receiving no potash additions and having, of course, much lower corn yields. Apparently the potassium content of the Dunkirk and Maumee fine sands is not so readily assimilated by corn seedlings as by wheat seedlings (table 10).

The phosphorous assimilation is no greater and shows no larger variation than in the wheat series, there being no appreciable assimilation above the seed content as shown by the silica sand check. In many cases the soil cultures fall below the check plots.

Although in a previous test (1), corn appeared to be a better indicator than wheat of potassium availability, the data for this series do not corroborate the

TABLE 8

Comparison of potassium and phosphorous assimilation by the corn plant using the Neubauer method, with acid-soluble potassium and crop yields

PLOT NUMBER	SOIL TREATMENT	K IN SOIL	CORN YIELD 1919–1923	K ASSIMILATED	P ASSIMILATED
		p.p.m.	*bu.*	*mgm.*	*mgm.*
1	None	23	33.25	14.19	13.65
2	P_2O_5	17	34.48	12.14	13.85
3	P_2O	36	47.16	18.49	14.09
8	$P_2O_5 + K_2O$	30	53.71	12.94	13.78
11	$P_2O_5 + K_2O + N$	31	58.67	10.57	13.45
	Dunkirk, Virgin	36	.....	9.96	13.04
	Dunkirk, Crop Experiment	53	.....	9.76	11.93
	Dunkirk, potato then pasture 15 years	32	.....	9.65	12.20
	Maumee Virgin	14	.....	10.73	11.32
	Silica sand check	..	.....	8.96	12.67

former results. The previous test involved only 5 plants, whereas this series was run with 25 plants to the pot more nearly to attain a starvation condition as advised by Neubauer (15, 16). It is probable, therefore, that the favorable results obtained previously were due to more nearly optimum growth factors than are provided for in the seedling method as devised by Neubauer.

A soybean series was also grown, 25 seeds being used to the pot, as for corn. The results which are of particular interest are given in table 9. The potassium assimilation does not vary in the same direction as for corn and wheat.

The higher potassium assimilation of soybeans follows the fertilizer treatment. It will be noted that the potassium assimilation is larger from the complete fertilizer plot and the plot that has had addition of phosphorous and potassium. Soybeans as compared with wheat and corn have also indicated a greater potassium availability for the sandy soils.

Although it may appear from these results that the soybean is more satisfactory than the other plants for indicating variations in potassium availability,

TABLE 9

Comparison of potassium and phosphorus assimilation by soybeans with the acid-soluble potassium in soil

PLOT NUMBER	SOIL TREATMENT	ACID-SOLUBLE K IN SOIL	K ASSIMILATED	P ASSIMILATED	P IN SEED*
		p.p.m.	*mgm.*	*mgm.*	*mgm.*
1	None	23	35.62	13.11	12.68
2	P_2O_5	17	30.80	9.50	10.62
3	K_2O	36	36.67	14.09	12.39
8	$P_2O_5 + K_2O$	30	39.28	14.32	14.46
11	$P_2O_5 + K_2O + N$	31	45.43	15.88	14.46
	Dunkirk-Virgin	36	39.68	11.21	13.57
	Dunkirk, cropped	53	44.31	15.30	14.75
	Dunkirk, potatoes, then pasture 15 years	32	40.25	13.72	14.16
	Maumee-Virgin	14	47.37	15.67	14.46
	Silica sand check	..	35.42	14.46	14.46

* Calculated from sand check.

TABLE 10

*Comparison of potassium assimilated in excess of pure sand checks by wheat, corn, and soybeans**

SOIL SOURCE	POTASSIUM ASSIMILATED IN EXCESS OF SAND CHECK		
	Wheat	Corn	Soybeans
	mgm.	*mgm.*	*mgm.*
Plot 1	1.20	5.23	4.60
Plot 2	3.50	3.18	4.78
Plot 3	6.76	9.53	6.43
Plot 5	2.89	....	....
Plot 6	3.90	....	....
Plot 8	6.96	3.98	4.00
Plot 9	5.40	....	....
Plot 11	4.35	1.61	10.15
Dunkirk-Virgin	3.86	1.00	6.56
Dunkirk-Cropped	4.59	0.80	9.03
Dunkirk-Pasture	2.85	0.69	5.69
Maumee-Virgin	5.23	1.77	12.09

* Because the soybeans are very high in potassium and the cotyledons were included in the analysis and since the number of soybean plants to the pot varied considerably, the values are here calculated to the number of plants to the pot.

it is not a suitable plant for the seedling test. Soybean seed has a high potassium content, and the possibility of wide differences in the amount in different lots of 25 seeds, together with the inability to secure a consistent germination

percentage renders the interpretable value of the data doubtful. It is apparent that the phosphorus assimilation does not vary consistently, nor is there a noticeable excess beyond that of the pure sand check.

Table 10 consists of the condensed data of these three series. In each case the potassium content of the pure sand check has been substracted from the remainder of the pots in the series in order more closely to compare the data. In the case of soybean, where the number of plants to the pot varied from 18 to 25, the value of a single plant grown on pure sand was determined and this value multiplied by the number of plants in each pot before substraction. The variation for the three crops is shown graphically in figure 1. The value

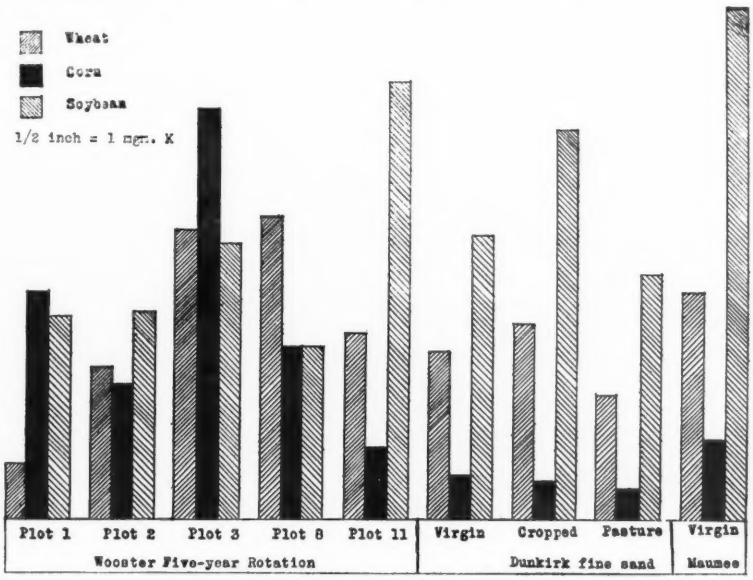

FIG. 1. POTASSIUM ASSIMILATED BY DIFFERENT CROP PLANTS

of these data consists largely in the evidence produced that no one plant, such as rye, used by Neubauer can serve as an indicator of the availability of any given nutrient for all plants. There exists no consistent relation between the assimilation of potassium by the three plants, corn, wheat, and soybeans upon the same soil.

Comparison of results with those obtained by Neubauer

Since Neubauer (16) has grown his rye seedlings on soils which for 30 years were under a system of fertilizer treatment similar to that given for an equal period to the soils used in the present study, a comparison of the two sets of data may be made as shown in table 11.

Although the data referring to the present study are for tops only, even should a reasonable allowance be made for the potassium in the roots, the results would in all cases still be only one-fifth to one-tenth as large as Neubauer's. There is also no evidence of correlation between the plot treatment and the potash assimilation of the two series of soils. In general, it

TABLE 11

Comparison of results with those obtained by Neubauer

KIND OF FERTILIZER USED	PRESENT STUDY—K ABSORBED BY			RESULTS OF NEUBAUER—K ABSORBED BY RYE
	Wheat	Corn	Soybeans	
	mgm.	*mgm.*	*mgm.*	*mgm.*
Unfertilized	1.20	5.23	4.60	29.1
P_2O_5 only	3.50	3.18	4.78	26.2
K_2O only	6.76	9.53	6.43	56.0
N only	2.89	....	....	21.7
$P_2O_5 + NaNO_3$	3.90	....	....	25.5
$P_2O_5 + KCl$	6.96	3.98	4.00	61.9
$KCl + NaNO_3$	5.40	....	....	57.5
$KCl + NaNO_3 + P_2O_5$	4.35	1.61	10.15	59.4

TABLE 12

Variation in potassium absorption within the duplicates of a single series—corn series

POT NUMBER	SOIL	NUMBER OF PLANTS	WEIGHT OF PLANTS	POTASSIUM ASSIMILATED	DIFFERENCE IN WEIGHT
			gm.	*mgm.*	*mgm.*
1	1	25	1.6610	14.31	
2		25	1.5341	14.07	0.24
3	2	25	1.5082	13.75	
4		25	1.2784	10.53	3.22
5	3	25	1.5790	15.92	
6		25	1.6116	21.07	5.15
7	8	25	1.5440	13.02	
8		25	1.5697	12.86	0.16
9	11	25	1.5154	10.21	
10		23	1.1038	10.93	0.72

must be said that the small absolute values for potash assimilation obtained in the present study, and the relatively large errors involved due to the variation between duplicate pots in a series render the value of the method very doubtful as applied to soils of the character studied.

The variation between duplicate pots, which are often as great as that between two different soils, can be explained only on a physiological basis, since

the weights of the plants grown in duplicate pots are remarkably uniform for wheat and corn. It is probable that a series of physiological factors involving inheritance and environment may be involved and these, in such an experiment as this, are beyond control. An attempt to control heritable variations was made, particularly in the case of corn, by using Burr Leaming, a double cross of inbred strains. Wheat and soybeans, being naturally inbred, should be fairly homozygous for growth factors within a given variety, though undoubtedly a pure line selection would be better than a variety.

Environmental factors might be better controlled by the use of artificial light and a constant temperature case. Neubauer (15, 16), however, has indicated that light is not an important factor, and Gunther (7) has confirmed this statement since he found but slight variation in potassium and phosphorous assimilation when the light was varied from complete darkness to full daylight. Wiessman (21) apparently disagrees with this, since he states that the stronger the light the greater is the influence upon seedling growth and nutrient assimilation.

Gunther (7) has also shown that the hydrogen-ion concentration of the soil does not materially influence the assimilation of nutrients by the seedling. This seemed to hold true in the present study, where there was no apparent relation of assimilation to the pH value of the soils used.

CONCLUSIONS

1. An investigation of the seedling plant method of determining the available soil nutrients indicates that the method devised by Neubauer is not generally applicable.

2. No one plant has been found which will indicate availability for all kinds of crop plants.

3. The error between duplicate pots is often of the same magnitude as the difference between the various soils under investigation.

4. Variations in potassium absorption were neither large enough nor sufficiently consistent to serve as a guide to the potassium requirements of the soils studied.

5. Contrary to Neubauer's results, no variation in phosphorous assimilation was found.

6. It may be possible so to standardize the seedling plant method that it may serve as an index of availability but it is believed that physiological limitations may exist which will be found insurmountable.

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THE POSSIBLE RÔLE OF IRON DEPOSITING BACTERIA IN THE FORMATION OF HARD-PAN

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The presence of a layer of impervious material beneath the surface of a soil is usually a limiting factor in plant growth. True, there are instances where agricultural plants grow with extraordinary success in regions where a subsurface stratum of this character is known to exist, but usually such a region is considered to offer little prospect of a continuously successful agricultural history. Hard-pan is a layer of just this sort. It is found as a calcarious pan, as well as one in which iron salts predominate. Of this latter, California has a considerable area, since of the 23,000,000 acres of arable land in the state, 2,000,000 acres are known, from soil surveys, to have an iron hard-pan below the surface. As hard-pan obstructs the penetration of water and roots, in the semi-arid conditions such as in California where roots of most agricultural plants penetrate to a considerable depth, blasting is often resorted to in an attempt to overcome the disadvantages of the pan.

Many explanations of the cause of hard-pan have been made in the past. That suggested by Hilgard (5) attributes the formation to a solution of materials at the weathering surfaces with a subsequent descent of these solutions to a lower level where the penetration of air "may cause the accumulation of the dissolved matter at a certain level year after year." But such a statement is, in fact, an empiricism and offers little satisfaction when the real explanation of the cause of pan formation is desired. Perhaps one of the most generally accepted of the theories is that which assumes successive stages of reduction and oxidation of the iron salts by the organic acids to a ferrous state with the subsequent precipitation of ferric salts through the action of air. Such a view is perhaps a little more definite than the older theories. Still more recently, however, attention has been directed toward the behavior of the colloids in the soil. With such newer knowledge, a theory has been developed by Morison and Sothers (7), who explain the pan formation by showing that in soils generally there is a favorable condition for the formation of a "sol" of ferric hydroxide and "humus." This "sol" on reaching the water level accumulates and during the dry months deposits as an irreversible "gel." This latter process also takes place through the action of electrolytes. These authors further say that

> as soon as the level exists at all, it is easy to imagine the rapid manner in which it (the level) will increase, and it is not difficult to conceive of the action described going on year after

year until the result called hard-pan is reached. On arrival of the wet season, the coagulated and desiccated colloids will not entirely go back into suspension as the colloidal character may well have been changed during the process of desiccation.

This explanation seems more logical, especially in view of the fact that the authors have been able to obtain these "sols" by washing ferric humus gels.

For the past several months this laboratory has been studying the iron depositing bacteria in relation to their occurrence in milk and dairy products. The writer's attention was first drawn to their general importance through the reading of Harder's (4) paper, in which he gives rather conclusive proof of the possible formation of certain sedimentary iron ores through the agency of the iron depositing bacteria. It was thought that they might as well be a factor in the formation of iron hard-pan which is so prevalent in the west. It is of great interest then to find on reading the paper by Morison and Sothers (7) at the end of their discussion a statement that

it is conceivable that some of the iron bacteria may play a part in the formation of pan, because that will be the only layer which will hold enough moisture for their existence. It is possible that, in the absence of much organic matter, organisms might use the humic acid combined with the iron as a source of energy, and leave the iron in the form of ferric hydroxide. The authors, however, consider that it is possible to account for the formation of pan without the intervention of living organisms.

This statement is made without apparent experimental evidence, and it seems likely that had published evidence existed, the authors would have cited it. To this might be added a recent contribution by Swinerton (8) which, again, is unsupported by experimental evidence but nevertheless shows the trend of thought concerning the iron depositing bacteria. Describing the finding of iron bacteria in Yosemite Valley, he says that

Bacteria, iron bacteria, among many other forms, may be important factors in the cementation of sand and gravel materials. Such would be the logical conclusion to draw from the results of previous studies in bacterial deposition; not only does the activity of the low forms of life provide material for the mass of rocks themselves, but also the material for binding clastic sediments.

Although it is not felt that there is yet direct proof of the contention the author is about to make and, although much more work remains to be done, still it is felt that these observations might add significance to whatever knowledge has been gained concerning the process of the formation of hard-pan.

As long ago as 1836, Ehrenberg suggested that bacteria play an important rôle in the formation of bog iron ore. Molisch (6), Cholodny (2), Ellis (3), and Harder (4) have all worked with these organisms, publishing descriptions of them and of their physiological reactions whenever they were able to propagate them artificially, which is difficult to accomplish. The characteristic reaction seems to be a precipitation of iron salts, usually the hydroxide from solutions of iron. Winogradsky claims (9, 10) that this deposition is a vital process, the organisms receiving their energy from the

reaction, although of recent years the tendency has been to consider that the deposition is simply incidental to the life processes of the organism. Whatever the underlying principle of the precipitation, the fact remains that such a precipitation takes place. The organisms usually defined as the "iron bacteria" are not the true bacteria (*eubacteria*) but probably would be included under the family *Chlamydobacteriaceae* since they are sheathed and filamentous forms. These workers, however, have found that some of the common soil and water bacteria also are able to deposit iron from solution in a manner similar to that of the "true iron" types. The finding of such iron-depositing bacteria in the soils and water of California led to a study of the hard-pans of the state. Several hard-pans were obtained, and from a freshly fractured surface small amounts were ground off with a sterile drill into a medium which has the following composition, as described by Harder (4): K_2HPO_4 0.5 gm., $MgSO_4$ 0.5 gm., NH_4NO_3 0.5 gm., $CaCl_2$ 0.2 gm., $NaNO_3$ 0.5 gm., ferric ammonium citrate 10 gm., water 1000 cc., pH 7.0.

This was used as a broth as well as a solid medium. In figure 1 of plate 1 are shown four of the pans, one of which has two holes, the result of the sampling process. The powdered pan, placed in sterile petri dishes and in tubes of Harder's broth, gave results shown in plate 1, figure 2, and plate 2, figure 1, respectively. The colonies are reddish, irregular, and incrusted with a fine film of iron salts. The broth tubes show the typical deposition of the iron from solution. Incubation to obtain the typical reaction varied somewhat from three weeks to three months.

The numbers varied from a few hundred to many thousand to each gram of pan substance, but since no method of obtaining exact numbers has been evolved, the actual counts are not given.

Isolation of the organisms discloses the fact that rods and cocci both are found in the cultures. They precipitate the iron in pure culture, but at a considerably slower rate. As a class, they ferment the salts of the organic acids with a distinct shift of the hydrogen-ion concentration to the alkaline side. They thus conform to the alkali bacteria, a group of organisms found in milk, and described by Ayers, Rupp, and Clemmer (1). These organisms are being subjected to more careful study which will be reported in a later paper.

In addition to the foregoing, there is further evidence of the possibility of a biological phase in the formation of iron hard-pan when the pans are examined under a microscope. Under a low power dissecting microscope giving magnification of 60 diameters and with reflected light, the pans show a coarse open structure with numerous cavities. These cavities are sometimes seen to be filled with a cobweb-like formation, as is shown in plate 2, figure 2. Only two pans of the six examined showed this formation but it is mentioned as further evidence of the presence of such organisms in pan material. When these filaments are removed from the pan and further examined with the higher power microscope, they appear to be somewhat similar to the higher bacteria.

forms described by Harder and others. Plate 2, figure 3 shows them under a magnification of 900 diameters.

In hard-pan then, we have evidence of both a previous microbial life and a present life, both of which deposit iron from solution. Such facts are of considerable significance. It seems to the author that there is thus offered a plausible explanation of at least one factor in the formation of hard-pan. He has seen in many parts of California, along the roots of grasses, particularly of rice, long tubules of red material which are teeming with iron depositing bacteria. Could not the iron which is found in the pan be first precipitated by the organisms and thus carried to the level, which later forms the hard-pan itself? The imagination is not unnecessarily stretched by such a conception.

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PLATE 1

FIG. 1. Four of the hard-pans used in the studies.
FIG. 2. Typical fermentation of the iron depositing bacteria studied.

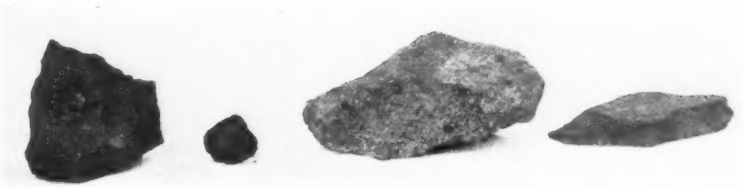

FIG. 1

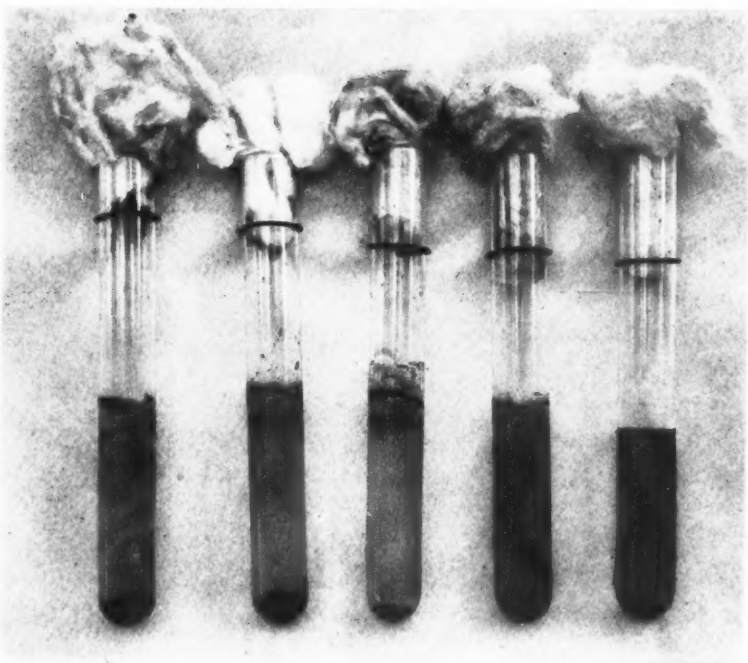

FIG. 2

PLATE 2

FIG. 1. Colonies obtained by plating powdered hard-pan on Harder's medium.
FIG. 2. Filaments within cavities of the hard-pan. Magnification 60×.
FIG. 3. Filament seen in figure 2 removed from the cavity and enlarged to 900×.

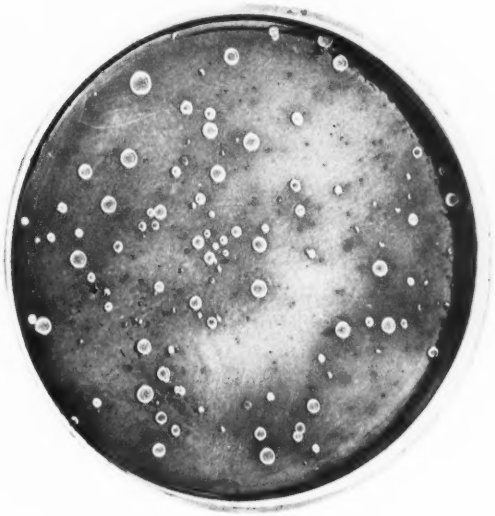

FIG. 1

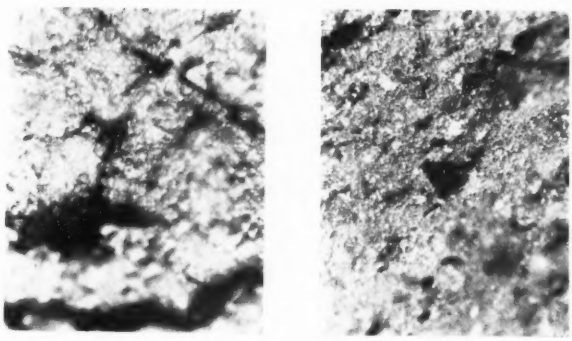

FIG. 2

FIG. 3

A STUDY OF THE SOILS OF HIDALGO COUNTY, TEXAS, AND THE STAGES OF THEIR SOIL LIME ACCUMULATION

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Hidalgo County, Texas, is located in the southernmost part of the state, about 30 miles west of the Gulf of Mexico, and adjacent to the Rio Grande, which divides it from Mexico. The ninety-eighth meridian of west longitude passes through the eastern part of the county.

The apex of the Rio Grande delta begins near the western edge of the county, the triangle on the American side widening gradually at first, then more rapidly, until at the eastern edge of the county the area of alluvial deposits, including those in both first and second bottom positions, is more than 25 miles wide. The greater part, if not all, of the remainder of the geological material underlying the soils of the county are included in a huge alluvial fan, deposited by drainage waters flowing over the region from the highland northwest of the Rio Grande basin. All of the geological deposits from which the soils of the county have been developed are thus of fluvial origin. The soils on the recently deposited and more or less frequently overflowed alluvial plains are identical with the alluvial deposits, but the rest of the soils of the county have characteristics of great significance, which the alluvial soils do not have. The geological deposits from which the soils in all parts of the county have been developed were, and where not subsequently changed are, calcareous.

The average annual rainfall of Hidalgo County ranges from less than 20 inches in the western part to 22½ inches in the eastern part. Thus the soil material under discussion has existed entirely under semi-arid and semi-humid conditions.

The soils of the county vary from young to mature, the latter being soils which have well developed profiles. The youngest soils of the county, measured in terms of the imperfection of their profile development, are found in the Rio Grande and Harlingen series, which exist as strictly first bottom soils, subject to ordinary overflows by the Rio Grande. Next older are the Laredo soils, existing as natural levees, mounds, and ridges in the first bottom of the river, and subject only to overflow by floods higher than the average. The Hidalgo and Victoria soils occur on terraces or second bottoms, and have had time to develop moderately well defined but incomplete profiles, whereas the Brennan, Willacy, Duval, and Nueces soils have developed profiles that seem to have attained the features of maturity for the environment in which they have developed.

SOIL SERIES

Short descriptions of these soils as found in Hidalgo County follow:

Rio Grande series. Dark brown to brown soils, overlying brown to light brown subsoils. Material of varying colors and textures frequently interstratified. Calcareous from surface downward. Topography flat to nearly level. Drainage only fair to good. First bottom, subject to ordinary overflows.

Harlingen series. Ashy grayish brown to grayish brown soils, underlain by ashy grayish brown to grayish brown subsoils. Soil and subsoil colors brown when moist. Calcareous from surface downward. Topography flat to nearly level. Drainage only fair to poor. First bottom, subject to ordinary overflows.

Laredo series. Brown or light brown to slightly chocolate brown soils, the subsoil being light brown to yellowish brown. Layers of lighter texture than the surface are generally found within three feet of the surface. Calcareous from surface downward. Levee positions or mounds or ridges in first bottom. Subject only to highest overflows of river. Drainage fair to good. Topography nearly level to slightly moundy.

Hidalgo series. Soils brown to slightly dark brown, overlying a friable brown to light brown subsoil which passes through yellowish-brown into a buff or pinkish-buff highly calcareous layer within 3 feet. Soil is always calcareous above 18 inches and generally from surface downward, lime content increasing with depth. Second bottom or terrace position. Nearly level to gently undulating topography. Drainage good as a rule.

Victoria series. Soils dark brown to nearly black, overlying material identical with the lower material of the Hidalgo series. Position, drainage, and topography similar. Soil lime characteristics identical with that of the Hidalgo soils. Eastern correlative of Hidalgo soils.

Brennan series. Grayish brown to brown soils, overlying brown, friable subsoils, becoming light brown or yellowish brown within 3 feet. Not generally calcareous above 30 inches, though sometimes below 18 inches. Below 3 feet a buff-brown or pinkish-buff highly calcareous clay loam is found, which continues to caliche, found at an average depth of 6 feet. Well drained. Gently undulating topography.

Willacy series. Dark brown soils, overlying brown, friable subsoils, becoming light brown or yellowish-brown within 3 feet. Below 3 feet a buff-brown or pinkish-buff highly calcareous clay loam is found, which continues to 10 or 20 feet, when it passes into yellowish-brown to yellow sand. No caliche under these soils. Not generally calcareous above 30 inches, though sometimes below 18 inches. Well drained. Gently undulating topography. Eastern correlative of Brennan soils, except for absence of caliche.

Duval series. Brownish-red to light reddish-brown soils, overlying non-calcareous, friable, light red to red subsoils. Caliche at 3 to 6 feet. No effervesence with hydrochloric acid above caliche. Topography nearly level to gently undulating. Drainage good.

Nueces series. Light brownish-gray to light grayish brown soils, underlain at from 2 to 6 feet by a heavy bluish-gray clay mottled yellow and sometimes red. Underlain at from 4 to 8 feet by caliche. Non-calcareous above caliche. Topography nearly level to undulating, slightly dune-like in places because of reworking of surface material by winds. Drainage good to excessive.

The average annual rainfall of 20 to 22½ inches to which these soils have been subjected since their deposition has been insufficient to remove the soil carbonates present in the soils when they were deposited or those carbonates which have developed through the normal chemical processes continually going on

within the soil mass. These soils, however, vary with age as to the presence and absence of lime in the soil, and the degree to which the leaching and accumulation of the soil carbonates has gone on.

The soils of the county may be divided into two groups on a basis of the presence or absence of carbonates in the upper soil horizons. Using an arbi-

FIG. 1. SKETCH MAP OF HIDALGO COUNTY, TEXAS, SHOWING THE LOCATION OF ITS MAJOR SOIL AREAS

Scale, approximately 8 miles to 1 inch

trary limit of 18 or 20 inches, those soils having soil lime in the horizons above include the younger soils lying at the lower elevations; namely, the Rio Grande, Harlingen, Laredo, Hidalgo, and Victoria soils. Those soils in which no lime is found above that limit are the older, higher lying soils of the Brennan, Willacy, Duval, and Nueces series.

Even within this broad classification there are distinct differences in the stages of leaching or lime accumulation, which for the most part vary with the age of the soils, the degree of accumulation corresponding in the main with the soil age. A minute examination of an exposed soil profile shows interesting factors, which will be given below.

STAGES OF LEACHING

First stage

In the most recent alluvial soils, those of the Rio Grande series, there is absolutely no evidence of leaching or greater accumulation of soil lime in any particular location or horizon within the section, approximately the same degree of effervescence with hydrochloric acid being obtained throughout. Neither are lime accumulations in the form of concretions or nodules of the smallest size visible. The same is true of the Harlingen soils in all respects, though there is noticed at depths of from five to more than six feet a layer of reddish material. If this reddish material is an evidence of accumulated lime or a distinct high lime bearing horizon it shows a stage of leaching in advance of the Rio Grande series. In this case, however, there is the possibility of this material being an older deposition of reddish material, which would offset the pinkish color found in most cases as incidental to a relatively high stage of lime accumulation in this general region, and indicate that the Harlingen has the same degree of leaching as the Rio Grande. The absence of leaching, or rather the uniform presence of lime throughout the soil profile may be termed the original or first stage in the degree of leaching and lime accumulation.

Second stage

The material of the Laredo series shows a fairly uniform reaction with hydrochloric acid throughout the section. There are visible, however, occasional small lime concretions or accretions, a slight cementation of the soil particles adjacent to old root channels and animal burrows, and a white mycelioid development of soil salts of calcareous nature embracing areas of a foot or more in diameter, generally located more than three feet below the surface. The fact of its greater age as evidenced by its higher position in the Rio Grande first bottom is paralleled by its greater advancement in the leaching of its soil lime and its accumulation in definite areas and forms. This accumulation in the form of minute lime concretions or accretions, a slight cementation of the soil particles in places, and the mycelioid development may be termed the second stage of the development of a definite zone of lime accumulation.

Third stage

A third stage in the degree of leaching and lime accumulation is found in an area of Brennan gravelly soils, found on a terrace in the western part of the county. Gravel and sand strata occur in this phase of the Brennan at a comparatively shallow depth, erosion having been somewhat active at this location. The soil horizon has not been fully leached, since it is still calcareous. A zone of lime accumulation, however, has developed, the carbonates occurring in three distinct forms: first, as a coating around the quartzitic gravel and sand particles, the coating ranging to $\frac{1}{16}$ inch thick in the case of the gravel; second, as a semi-cementing or cementing agency between the sand and gravel, giving the material the appearance of concrete, the term by which this cemented material is known; and, third, in a more or less pure indurated state, or hard caliche, in layers up to six inches in thickness, but of limited lateral extent. The stage of induration reached by the accumulated lime in this location is enhanced by its shallow occurrence, in which position a greater degree of oxidation occurs in a given time, with consequent greater induration. The degree of oxidation here is also increased by the open character of the sand and gravel as it occurred before the accumulation of the leached carbonates began. Under these conditions the degree of accumulation and induration of the carbonates originally present in the soil horizons is not characteristic of the soils of the county.

The characteristic third stage in the degree of leaching of the soil carbonates and their accumulation occurs in the soils of the Victoria and Hidalgo series. Here the soils effervesce with hydrochloric acid from the surface downward, but the strength of effervescence increases with depth, indicating a higher percentage of lime with depth. Small soft lime accretions or concretions are found in the soil mass beginning at from 12 to 18 inches, continuing downward to depths of more than 10 feet, and increasing in size and numbers with depth. At about 12 inches in depth the soil mass in both series becomes brown in color, and with increasing depth the color becomes lighter, passing through light brown and yellowish-brown into a buff or pinkish-buff clay loam at about three feet. This latter material continues without great change to depths of as much as 60 feet according to material taken from wells. Some soft white lime accretions or concretions up to an inch or more in diameter are encountered at lower depths. The buff or pinkish-buff material represents the point of highest carbonate accumulation in soils having reached this stage of leaching and accumulation, and is characteristic of this stage of development of the zone of soil lime accumulation over large areas in southern and western central Texas. Upon exposure to the atmosphere the originally soft white lime accretions or concretions mentioned above become hard on the outside, and, with sufficient time, all the way through. Likewise, the surface of the

buff material becomes slightly hardened and cemented, standing in perpendicular walls for long periods without caving. This hardening on exposure represents a gradation toward the fifth or ultimate, and maximum, degree of leaching of the soil carbonates and their accumulation in definite strata.

Fourth stage

The fourth stage in the degree of leaching of the carbonates from the soil and their accumulation in a definite zone is found in those areas covered by the greater part of the Brennan, and the Willacy soils. Here the soil above 30 inches to 3 feet has been entirely leached of carbonates, no effervescence occurring with hydrochloric acid above these depths. At these depths there is found a yellowish-brown to buff-brown or pinkish-buff layer, identical with that found under the Victoria and Hidalgo soils, which is highly calcareous, and contains hard and soft white lime accretions and concretions varying from $\frac{1}{8}$ to $\frac{3}{4}$ of an inch in diameter. Also there is found a semi-cementation of the material which has filled the smaller old root channels and animal burrows, and whitish seams of highly calcareous material in the finer root channels. In the case of the Brennan soils this highly calcareous material passes at about 6 to 8 feet into white caliche, somewhat indurated in the upper few inches and ranging from 6 to 12 or more feet in thickness. In the eastern correlative of the Brennan soils, the Willacy, this caliche is absent, the buffish calcareous material extending to depths of 18 to 40 feet from the surface, when it generally passes into a yellow calcareous fine sand. The buff material is said by well-diggers to be full of seams of semi-hard, white calcareous concretions or accretions which range up to an inch or more in diameter. It is probable that the higher rainfall under which the Willacy soils exist has had considerable influence on the absence of the caliche layer under this soil, the fine sand occurring beneath the buff layer under the Willacy possibly permitting a wider distribution of the carbonates leached from the soil.

It is distinctly to be understood, however, that the thick caliche bed found under the Brennan and other soils is not regarded as the result of lime leached from the soil alone. This great accumulation must have been aided by subterranean waters of high carbonate content.

Fifth stage

The fifth, or ultimate stage of development of the lime accumulation zone in Hidalgo County is found in the Duval and Nueces soils. In these soils generally no effervescence is obtained with hydrochloric acid above the caliche, and in the exceptions only an inch or two of yellowish or buffish material which is highly calcareous is found above the caliche. This represents the nearest approach to the characteristic highly calcareous buff layer mentioned in connection

with the second, third, and fourth stages. The caliche is found at depths of from 3 to 8 feet under nearly all of the Duval and Nueces soils, being shallower as a rule under the Duval. Especially where it occurs at shallow depths the upper few inches of the caliche is quite hard. Below the hardened caliche will be found a semi-indurated caliche, from 8 to 18 feet thick, in pits, from which it had been removed for road building material. The semi-indurated caliche crumbles fairly readily to particles measuring from one-half to an inch in diameter when newly exposed, but hardens on exposure. Very little change is noted in the character of the caliche throughout the depth of its accumulation.

Where the caliche was penetrated in the northern part of the county there was found a blue, very compact, heavy clay shale, highly calcareous, which seemed to extend to considerable depths.

The face of exposures studied from the level of the indurated lime layer to the surface of the blue clay shale was about 20 feet thick. Aside from the difference in the degree of hardness of the upper part, the upper half or more of this caliche layer presented a practically uniform appearance, and the face exposed had an irregular structure. Beneath this uniform material there were found to be areas of varying extent where there was a columnar structure—alternating columns of caliche extending without change, from the solid mass above down to the level of the blue clay shale, and columns of material of the blue clay shale material extending upward from the shale mass into the mass of caliche. These shale clay columns appeared to be somewhat changed from the underlying mass due to a slight induration and by an accumulation of the whitish lime at the edges of the perpendicular and horizontal cracks which appeared to divide these shale columns into clods approximately an inch in diameter. In general this columnar structure gave the appearance of stalactites of caliche extending from the mass of caliche above into the clay shales beneath, and of stalagmites of the clay shale material extending from the basal material into the mass of caliche. Isolated masses of the clay shale material were found surrounded by caliche, and large masses of caliche were also found entirely surrounded by the clay material.

There is no doubt that the upper part of the caliche mass represents an indurated accumulation of soil lime caused by percolation of soil water downward. The columnar structure seems to indicate either a downward percolation of lime-charged waters through cracks in the clay and deposition of the accumulated lime on the way down, or the rising of subterranean calcareous waters and the accumulation of the material in the columns and the lower part of the caliche mass in this manner.

It will be particularly borne in mind that the five stages of leaching of the soil mass of its carbonates and their accumulation in definite zones as described

above occur within fluvial soils derived from the same or very similar material, under similar conditions of rainfall in a north and south zone less than 40 miles long. The soils are of varying age and elevation, the youngest soils being found at the lowest elevation and the oldest at the highest elevation, respectively. And as has been shown above, the degree of the leaching of the soil of its carbonates with the attendant accumulation in a definite horizon is definitely related to the age of the material.

SUMMARY

Hidalgo County, Texas, is located in the southernmost part of the state, 30 miles west of the Gulf of Mexico, and along the Rio Grande. The ninety-eighth meridian of west longitude passes through the county. The rainfall of the county varies from less than 20 inches in the western part to 22½ in the eastern part, giving a semi-humid to semi-arid climate.

The apex of the delta of the Rio Grande begins in the western part of the county, and widens out to more than 25 miles in the eastern part. All of the geological deposits of the county are of fluvial origin, those of the true delta being alluvial, and most of the remainder lying as a huge alluvial from northwestern highlands. The soils on the overflowed alluvial plain are identical with the alluvial deposits, and the remainder have definite characteristics. The geological deposits, where unchanged, are calcareous.

The soils of the county vary from young to mature, depending on the perfection of their profile development. The first bottom Rio Grande and Harlingen soils are youngest; the Laredo occurring in natural levee or high first bottom positions are next; the terrace Victoria and Hidalgo soils with moderately well developed but incomplete profiles are next; and the Brennan, Willacy, Duval, and Nueces soils have attained the mature profile for this section.

The youngest soils have absolutely no evidence of leaching or greater accumulation of soil lime in any particular horizon within the section.

The Laredo soils show a fairly uniform reaction with hydrochloric acid throughout the section. There are, however, small lime concretions and accretions, a slight cementation of soil particles adjacent to old root channels and animal burrows, and a white mycelioid development of calcareous salts at 3 feet below the surface.

The third stage in degree of leaching and accumulation of soil carbonates occurs in the terrace Victoria and Hidalgo soils. These soils effervesce from the surface downward, the effervescence increasing with depth. Small soft lime accretions or concretions are found in the soil mass below 12 to 18 inches, continuing to more than 10 feet, and increasing in size and numbers with depth.

The fourth stage is found in the southern part of the area of Brennan and Willacy soils. Here the soil above 30 to 36 inches has been entirely leached of

carbonates. Below this is found a yellowish-brown to buff-brown or pinkish-buff layer, similar to the lower material of the Victoria and Hidalgo soils, which is highly calcareous and contains much soft white lime in large and small accretions and concretions. Caliche, somewhat indurated in the surface, is found at 6 to 8 feet below the Brennan soils but is absent under the Willacy soils.

The ultimate stage of lime development is found in the Duval and Nueces soils. No effervescence occurs above the caliche, which is found at depths of 3 to 8 feet and is quite hard in the surface at the shallower depths.

These five stages of leaching of the soil mass of its carbonates and their accumulation in definite zones occur within fluvial soils derived from the same or very similar materials, and occurring under similar conditions of rainfall in a north and south zone less than 40 miles in length. The stages are definitely linked with the age of material.

PLATE I

FIG. 1. The third stage of development. The section shown is about 15 feet thick. Soil lime is present from the surface downward, but a definite accumulation begins at about 3 feet, in the light brown to buff material. The small lime accretions or concretions are plainly evident, showing the beginning of soil lime accumulation in a definite stratum, extending from about 4 to 12 feet.

FIG. 2. Caliche bed over 15 feet thick. Where these beds are found the soil section above has been leached of all soil carbonates as a rule. The upper few feet of the caliche has been indurated, whereas that below is fairly chalky, and breaks up into aggregates about an inch in diameter.

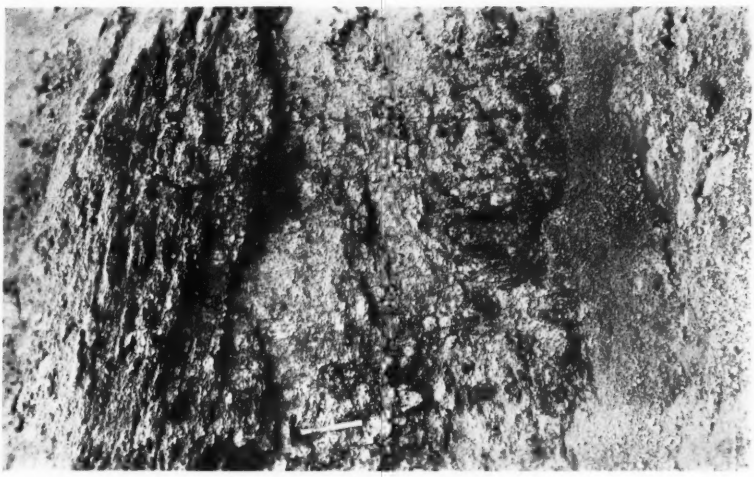

FIG. 2

FIG. 1

A STUDY OF THE COLLOIDAL FRACTION OF CERTAIN SOILS HAVING RESTRICTED DRAINAGE

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Received for publication August 25, 1926

The movement of water in soils is due to a combination of many factors, among which resistance offered by the amount, composition, and state of colloids present is of chief importance. The other factors commonly listed as affecting percolation are of relatively less importance, or are corollary to the effect of the colloid.

A modern concept of the soil would be to regard it as including a mineral skeleton and a fleshy colloidal covering. If a soil were 99 per cent sand and 1 per cent colloidal clay, the surface area of this finer fraction would be greatest. The colloidal material present is responsible for the shrinking and swelling, the physical absorption, the chemical adsorption, and the base exchange. Any effective applications used to improve soil conditions will accomplish this largely by modifying the state of the colloid present.

When water is applied to a soil, the physical qualities of the soil may be greatly modified. Shrinkage cracks which may affect percolation temporarily or locally are soon swelled shut. Solutes are dissolved and an approximate equilibrium is soon found between the solid phase and the liquid phase, the latter of which is called the soil solution. Removal of solutes like calcium by plant absorption is sufficient to result in a heavier soil structure. If sodium or other monovalent ions invade the system, as when brought in with irrigation water, some increase in deflocculation may be expected. Only a dynamic equilibrium will be found in the soil under crop and the state of the soil colloid will be affected by the kind and concentration of solutes present. There must be some drainage to remove from the system the nonessential deflocculating ion, such as sodium. With the aging of soil, in time a concentration of colloidal material will come about in certain horizons of the soil profile, as best exemplified in mature or aged soil profiles. "Hard pan" layers thus developed may require special treatment. For soil moisture study it would seem best to sample mature soils according to soil horizons and to express results in their ratio to the hygroscopic coefficient.

In a study of percolation of water through soils having a high clay content and restricted drainage, taken from widely separated sections of Oregon,

[1] Released with the approval of the Director, Oregon Experiment Station. Read before American Association of Agriculture Engineers, Lake Tahoe, Cal., June, 1926.

attention has been given to percolation, flocculation, titration, and ion migration or cataphoresis. The soils used included Dayton silty clay loam soil, a heavy alkaline loam from Vale Experiment Field, a colloidal clay from Lower

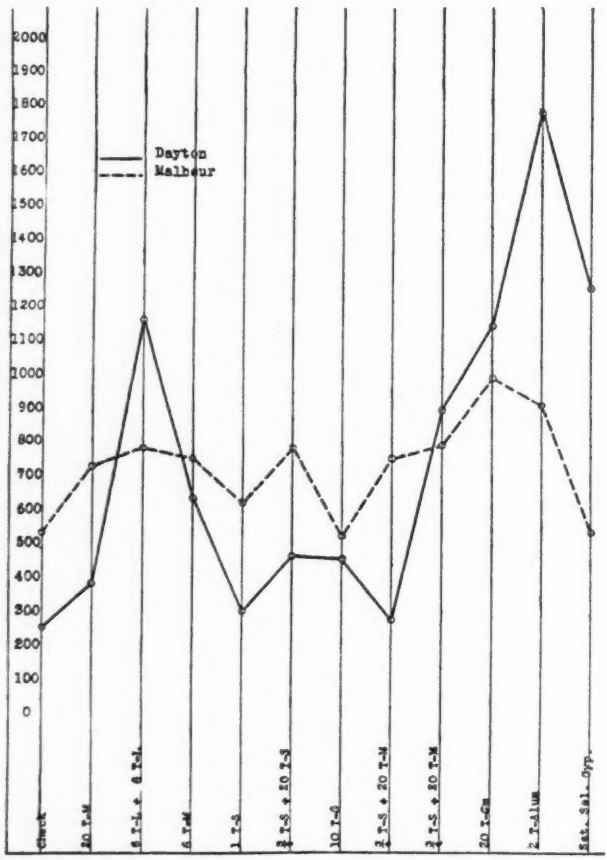

FIG. 1. MAXIMUM PERCOLATION ON DAYTON AND MALHEUR SOILS

Klamath Lake bed, and a gelatinous muck from Lower Klamath Marsh. These soils are described elsewhere (2, 3).[2]

[2] The work was done in the Soils Laboratory of the Oregon Experiment Station with the coöperation of two graduate students.

PERCOLATION TRIALS

Twelve 3-gallon jars of Dayton and twelve of the Vale soil were treated as indicated by figure 1, and the maximum rate of percolation was determined. The diagram shows, as found by Young (4),

> that all treatments were better than no treatment at all, but that some excelled more than others. The greatest increase in rate of percolation came from the treatments of lime and manure, sulfur and manure, green manure, alum, and a saturated solution of calcium sulfate.

The benefit from the treatment was undoubtedly due to a change in the colloidal state of the clay.

FLOCCULATION

Flocculation studies were qualitative in nature. The solutions used consisted of aluminum chloride, di- and tri-valent sulfate, ferric phosphate, ferric chloride, calcium sulfate, magnesium chloride, lime-water, alum, ammonium nitrate, and three acids—sulfuric, nitric, and hydrochloric. Ammonium hydroxide was used as a dispersing or stabilizing agent. The nearly pure colloid was prepared by churning the soil with several parts of distilled water in a 5-liter bottle, and after some days sedimentation, centrifuging the supernatent suspension through a supercentrifuge. The colloid was collected on a Pasteur-Chamberlain filter candle and thoroughly washed. It was then of the consistency of axle grease. In the flocculation study, 10-cc. portions of the stabilized suspensions of these colloids were used.

It was found that the rate of flocculation of colloids corresponded very closely to the valence of the ion used and the size of the coagulated particles had filled out very directly as the valence of the ion used. When monovalent cations were used a very finely divided precipitate slowly settled out. Lime-water caused flocculation almost as rapidly as alum or other trivalent ions. Flocculation by acids and calcium was more rapid when the solution had been previously made alkaline with ammonium hydroxide. Both colloids showed a close relationship of flocculation to the valency and atomic weight. The beneficial effect from the use of sulfur on the physical condition of the soil of Vale Experiment Field is believed to be due to oxidation of sulfur to sulfuric acid, and the resultant neutralization and increase in calcium dissolved by this acid and brought into solution, the calcium probably being the direct flocculating agent rather than the sulfate ion.

TITRATION STUDIES

Results of titration studies of colloids from these four soils are shown in figure 2, and all show similarity. Differences are attributable to difference in composition and concentration of alkali or acid. At the high acidity it appears that tri-valent iron and aluminum still remain unreplaced from the

colloidal complex. Flocculation may be considered as a neutralization and a cation may be expected to accomplish this for a negatively charged colloid. Hydrogen ion is nearly as effective as bivalent cations for flocculation.

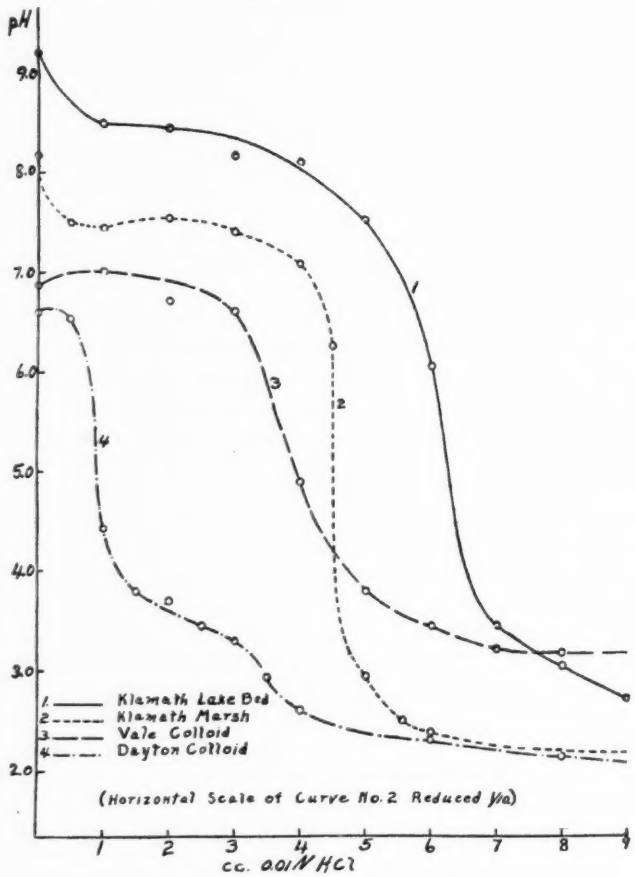

FIG. 2. TITRATION CURVES OF SOIL COLLOIDS

MIGRATION STUDIES

Migration or cataphoresis trials were made for these colloids. At reactions from pH 10.0 to pH 2.5 all these colloids were found to migrate in an electric field as though having a negative change. It was thought possible that the organic colloid from Klamath Marsh may manifest an isoelectric point, but no indication of this was found.

LYSIMETER STUDIES

Lysimeter studies have been maintained at the Oregon Experiment Station for several years (3). By working with soils of different textures, both with and without crop, it has been found that percolation loss is diminished or eliminated with increasing very fine texture under moderate irrigation and that the crop greatly reduces percolation. At Corvallis, lysimeters filled with two heavy soils; namely, Dayton and Willamette silty clay loams, and then treated some with lime, others with manure, others with lime and manure, and still others untreated, are found by Higby (1) of this department to show that "in all cases lime and manure applications singly or in combination increased the flow of drainage."

FIELD TRIALS

In alkali land reclamation investigations at Vale, Oregon (2) about one ton sulfur or four to five tons of gypsum used with a light application of manure have been effective in improving the structure of sodium saturated "black alkali" land and have made possible the growing of good crops of rye and sweet clover. Alum has been less effective in the field than in laboratory studies. Copious irrigation and pasture growth in natural vegetation are giving promising economic results.

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BOOK REVIEWS

Grundzüge der praktischen Bodenkunde. By DR. HERMANN STREMME, Gebrüder Borntraeger, Berlin, 1926. 332 pp., 6 figs., 10 diagr. Price, unbound, R. M. 16.50; bound, R. M. 19.00.

The author of this book, the well known German pedologist, states in the preface that most of the textbooks of soil science devote too much attention to the soil profile and not enough to the surface of the soil, including soil mapping, and that they also lack the practical application of the subject. The book under consideration has been written to discuss largely these points, based upon the extensive experience of the author in mapping soil at Danzig, on the basis of climatic soil types; it embraces also a field study of soils in general. Laboratory methods of analysis are not described.

The author reviews the various soil types, the formation of soils under the influence of climate and ground waters, and then discusses in detail the preparation of soil maps, emphasizing throughout, the application of the results of soil mapping to practical agriculture.

A rather abortive attempt is made to discuss the soil organisms, which are soon dismissed by an indication that there is no single soil constituent which is not acted upon in one way or another by the soil bacteria and other organisms; the author then proceeds to discuss the ecology of higher plants. An equally inadequate attempt is made to discuss the nature of soil "humus," which is referred to merely as a mass of waste products of animal life. Among the soil animals, the earthworms are supposed to have been studied most, their rôle being of course that of "humus formers"—a theory current fifty to sixty years ago. It is also peculiar that a book on practical soil science should not consider the biochemical processes in the soil, although the author indicates that the distinct difference between soils and rocks is due largely to the presence of living organisms in the former.

It is about time that writers of textbooks which are devoted to the subject of soil science in general should consider the activities of the lowly organisms, whose rôle in soil processes is far reaching.

A more appropriate title for this book, which is invaluable to people interested in soil mapping, would be "Characteristics of Soil Mapping and its Application to Practical Agriculture."

SELMAN A. WAKSMAN.

Principles of soil microbiology. By SELMAN A. WAKSMAN, Associate Professor of Soil Microbiology, Rutgers University, and Microbiologist of the New Jersey Agricultural Experiment Station. Williams and Wilkins Company, Baltimore, 1927. xxviii, pp. 897, pl. 19, figs. 82.

Biologists in general and soil scientists in particular should be happy to learn of the publication of this brilliant presentation of the development and present status of the knowledge of the occurrence of microörganisms in the soil, their activities, and their rôle in soil processes.

The volume is divided into 32 chapters arranged under three main sections: (1) occurrence and differentiation of microörganisms in the soil, (2) isolation, identification, and cultivation of soil microörganisms, (3) chemical activities of microörganisms. Quite logically the activities of the microörganisms receive the most extensive and interesting treatment. Among the subjects treated the following may be of particular interest: the soil population—distribution, abundance, and methods of study; autotrophic bacteria; bacteria concerned in the numerous transformations of nitrogen; decomposition of organic materials with particular emphasis upon the influence of nitrogen upon the process; energy transformations in microbial metabolism; transformation of inorganic soil constituents; soil as a habitat for microörganisms causing plant and animal diseases; and soil inoculation. The volume is concluded very originally with a short review of the historical development of the subject. The subject material is replete with references to the literature and well illustrated by plates, line drawings, and graphs. The text is fortunately preceded by a list of some 200 reference books on sciences directly or indirectly related to soil microbiology. The reader has ready access to the text from indices of both authors and subjects.

The author has brought together the information on microörganisms and soil processes in such a manner that one can hardly fail to become impressed with the idea that soil microbiology is a well defined and important science. It is arranged not as a compilation but as a complete and well balanced critical presentation of the facts and ideas concerning the soil population. The method of treatment gives one a new insight into the interpretation of microorganisms as agents in the chemical processes in the soil environment.

Few of the profusion of books recently from the press seem destined to satisfy such a very evident need of long standing for a concise and readily available source of information on the subject. It should be received enthusiastically not alone by soil biologists but all soil scientists as well as individuals interested in biology from the point of view of the distribution and activities of the infinitely small organisms in their relations to soils and plant growth. It is hardly a text book for undergraduate students but rather a general reference text for teachers and research workers.

An unprecedented venture of this kind may justly be expected to be imperfect, but the author appears to have happily developed the subject material with the minimum distortion. The physical makeup is admirable. The

author's style is very readable and the text exceptionally free from errors for the first edition of a work which requires such great detail in preparation.

ROBERT L. STARKEY.

Methoden der Mikrobiologischen Bodenforschung. By SELMAN A. WAKSMAN, Associate Professor of Soil Microbiology, Rutgers University, and Microbiologist, New Jersey Agricultural Experiment Station. Berlin and Wien, 1927. Pp 149. A section of the *Handbuch der biologischen Arbeitsmethoden* of Abderhalden.

This volume shows the marked tendency of recent investigations in soil biology to embrace studies of many elements of the soil population. It includes methods of study of bacteria, filamentous fungi, actinomyces, algae protozoa, and to some extent other invertebrates.

In its preparation Chr. Barthel (Stockholm) contributed the material on cellulose decomposition and symbiotic nitrogen fixation, D. W. Cutler (Rothamsted) on soil protozoa and B. M. Bristol-Roach (Rothamsted) on soil algae. The material is arranged in three principal sections: (1) study of the microbial population of the soil as a whole, (2) isolation and cultivation of specific groups of soil organisms, (3) study of biological activities of pure and mixed cultures of soil organisms.

The presentation suggests the recent digression from the Remy-Löhnis methods of study of biological activities of soils. Direct, cultural, and biochemical methods of study of the soil population are outlined. Among the biochemical activities particular attention is applied to the decomposition of organic materials, nitrogen fixation, transformations of sulfur, and autotrophic processes in general. The importance and general application of the methods of study are suggested.

There is no tendency to present arbitrary "official" methods but rather workable procedures which may be useful to instructors and research workers in outlining student work and approaching new studies in soil biology.

ROBERT L. STARKEY.

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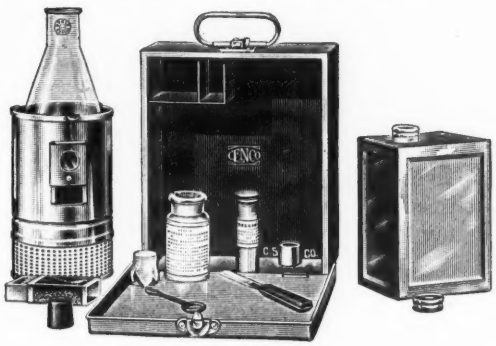

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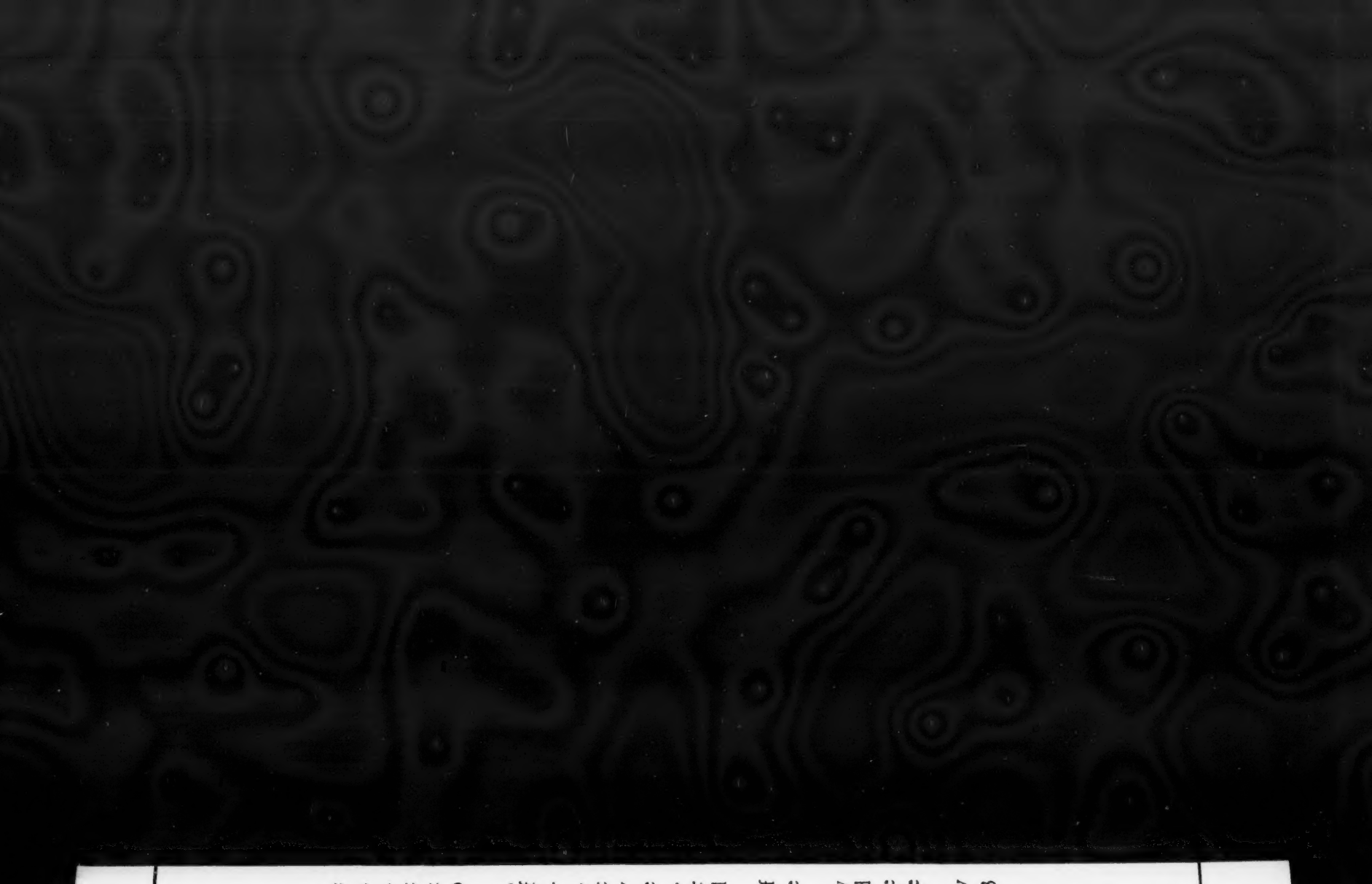

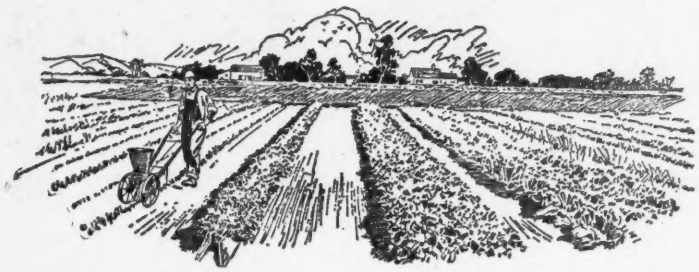

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